# Integrated Mission Design Center
# GLAST Mission Study

February 13, 1998

**NASA's Goddard Space Flight Center / Integrated Mission Design Center**

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# 1.0 Scope

## 1.1 Background

The Gamma-Ray Large Area Space Telescope study team, under the direction of Dr. Jonathan Ormes and study manager, Ms. Bonnie Norris requested a mission study be performed in support of their ongoing study effort. In the time frame of this effort, the IMDC was in its early stages of development. Consequently, the study did not include any grass roots costing effort. Costs however, are supplied for spacecraft components, launch vehicle options and ground segment.

# 2.0 Prework

## 2.1 Prework Briefing

The following 13 slides are the Prework Briefing, scaled to fit this document.

**GLAST**

**Gamma-Ray Large Area Space Telescope**

**www701.gsfc.nasa.gov/glast/glast.htm**

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**Science Matrix**

| Mission Objective | Performance Drivers |
|---|---|
| Identify and study nature's high energy particle accelerators through observations of active galactic nuclei, pulsars, stellar-mass black holes, supernova remnants, gamma ray bursts, and diffuse galactic and extragalactic high-energy radiation<br>Use the above sources to probe important physical parameters of the Galaxy and Universe that are not readily measured with other observations | Large area silicon strip detectors |

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# Mission Requirements and Constraints

**Mission Constraints**

| | |
|---|---|
| Target Lifecycle Cost Range: | <400 million |
| Operational Lifetime Requirement: | 2 years |
| Operational Lifetime Goal | 5 years |
| Launch Vehicle | Baseline Delta 7925 but can trade (foreign) |

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# Mission Requirements and Constraints

**Miscellaneous Mission Requirements**

| | |
|---|---|
| Safety Requirements | Standard |
| Contamination Requirements | Standard/ Class 10,000 |
| Mission Reliability Class | Class B or Class C with redundancy |
| Mission Technology Goals | Science Goals |

**Schedule Milestones**

| | |
|---|---|
| Phase A completion | 1999 |
| Phase B completion | 2001 |
| Instrument delivery | 2003 |
| Launch | 2004 |

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## Baseline Mission Architecture

| | |
|---|---|
| **Instrument Name:** | GLAST |
| Type | Solid State Gamma ray detector |
| Description and Operations | 3000 kg instrument with all sky survey mode and pointed observation mode: any direction, any time |
| Heritage & Maturity: | Follow on to EGRET |
| Unknowns/ Issues/ Concerns: | 1) Desire to be fully autonomous<br>2) C&DH architecture |
| Technology & development needs | 32 bit rad hard processor |

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## Mission Characteristics

| | |
|---|---|
| **Name/Identifier:** | GLAST |
| **Characteristics:** | Zenith pointing first one to two years of operation rocking back and forth to cover sky, with ability to interrupt and point (45 deg max slew in TBD seconds) at any time.<br><br>Final three years of operation pointed observations for up to 2-3 weeks at a time, will follow objects of interest<br><br>Potential to slew to secondary targets during orbit to avoid earth obscuration |
| **Orbit** | Nominal 600 km but can be traded<br>Need to avoid SAA |
| Orbit type | Circular with < 28.7 deg inclination<br>(0 degrees preferred) |
| Orbit knowledge/maintenance | Needed for timing but not critical ~ 1000 ft |

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# Mission Operations Concept

**Observatory Pointing**

| | |
|---|---|
| type (nadir, stellar, other) | zenith |
| primary observation(s) description | Measure arrival time, direction and energy of incident gamma rays |
| observation(s) duration | Hours to weeks |
| control system type | 3 axis stabilized |
| boresight pointing accuracy | 5 degrees |
| boresight pointing knowledge | <10 arc-seconds (1 sigma) |
| other axes pointing accuracy | 5 degrees |
| other axes knowledge | <10 arc-seconds (1 sigma) |
| stability | Must know on board real time |
| avoidance | None |
| slew requirements | Automatically slew (speed is a trade) to look at objects of interest. Fast slew is desired. |
| timing requirements | 1 usecond absolute desired<br>Maximum allowable is 10 usec |

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# Operations Concept Cont.

**Ground to Observatory Interaction**

| | |
|---|---|
| Maximum operating time without ground intervention | Eventually observatory will be "fully autonomous." In second operational mode, will be uplinking targets approximately every few weeks. |
| Describe any calibration modes that require ground interventions | Will be uplinking software often early in mission. |
| Scientific events that require change in instrument observations by ground intervention | When notified by other observatories of AGN flares will want to change pointing (approx. once a week)<br>Scientists will be alerted by a low data rate downlink of gamma ray bursts so they can inform other observatories |
| Acceptable delay between event and ground interaction | Immediate notification required as an alert (1 k byte) |
| Frequency of science events | Once/day max nominally few times a week |
| Ground station preferences | None |
| Contact time | Nominally downlink primary science data every day. No requirement for 100% recovery of data. |

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# Operations Concept Cont.

| | |
|---|---|
| **Data volume and Data processing** | |
| Average data rate | 250 – 300 kbps but would like to trade, would like the maximum rate down |
| peak rate | TBD – 4 mbytes/sec filtered by the computer |
| daily data rate (includes inst engineering, science and data formatting overhead) | 25.9 Gbits |
| Acceptable compression | TBD |
| Downlink rate if known | TBD |
| Uplink rate if known | 2 kbps (?) |
| Quick look data set required? | Yes, alert mentioned above and housekeeping |

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# Operations Concept Cont.

**General operations**

| | |
|---|---|
| S/C on board storage | Trade |
| S/C to Instrument Data requirements | Timing, position, attitude |
| S/C on board processing required | TBD |
| Ground station preference | Inexpensive |
| Level of autonomy | Full |
| New Technologies | Not adverse to new s/c technologies |
| **Other Mission Requirements** | Controlled re-entry required in < 25 years (breakup requirement) |

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## Instrument Description

| | |
|---|---|
| **Instrument Name** | **GLAST** |
| Data interface | TBD |
| **Mechanical** | |
| Mass | 3000 kg |
| CG | Low |
| Volume | 1.7 x 1.7 x 0.7 m |
| Field of View | 80 degree half angle with "sweet spot" of +/- 30 degree. Knowledge requirement is for the +/- 30 degrees. |
| Mechanical Accommodations: | No obstruction in instrument FOV.<br>No obstructions in +/- 20 degrees from perpendicular to base of inst.<br>Instrument grid may be part of s/c<br>Instrument CPU must be close |
| **Electrical** | |
| Peak/Average Power | Power is trade 650 W minimum would like 50% more |
| **Thermal** | |
| Interfaces | Grid stable to 1 deg C, cooled with heat pipes, radiator design critical |

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## Multi-instrument Mission Architecture

| | |
|---|---|
| **Instrument(s) Name:** | GLAST<br>Gamma Ray Burst instrument,<br>X-Ray monitor<br>Optical monitor |
| Unknowns/ Issues/ Concerns: | FOV, Mass?, power |

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# Trades

- Instrument power vs. science
- Inclination vs science
- Slewing speed vs. science
- Re-entry (propulsion needed?)
- Telemetry vs. science and on-board processing

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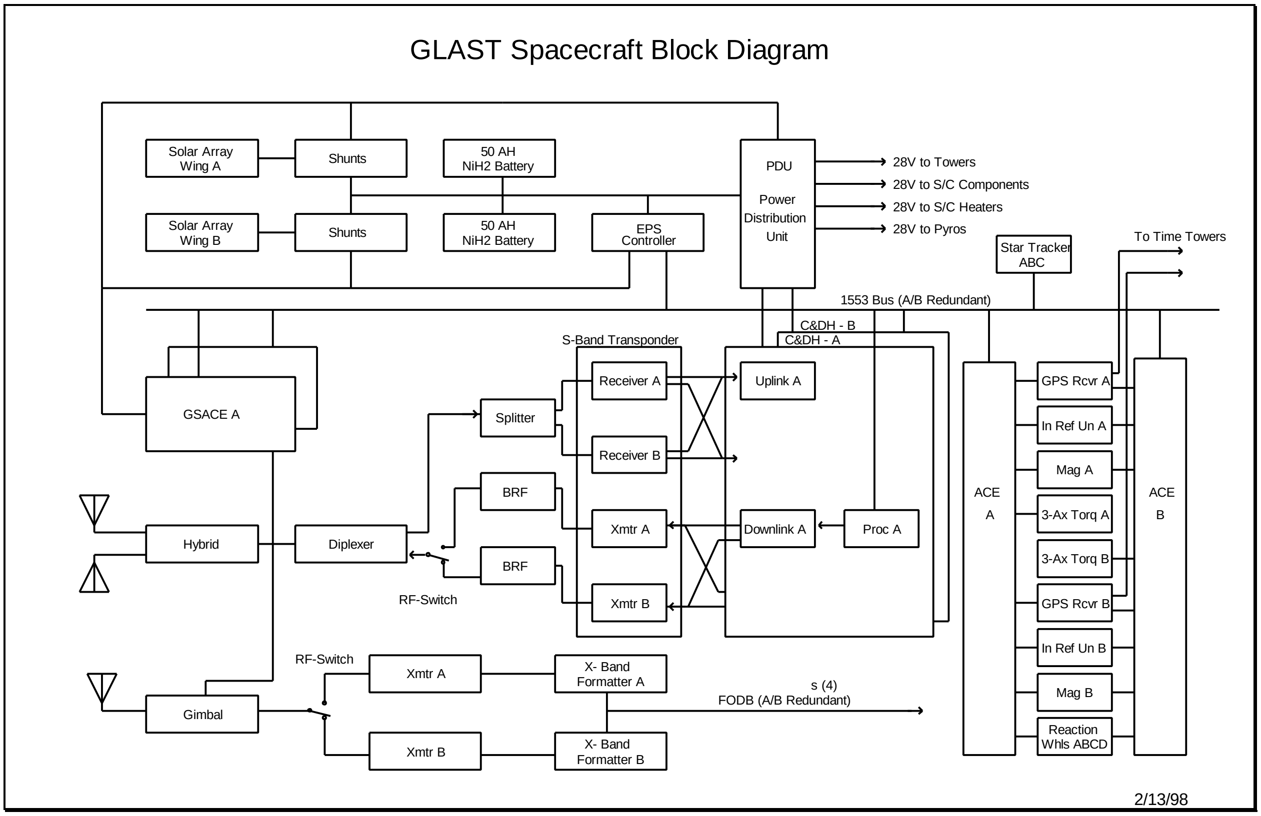
# 3.0 System Summary

## 3.0.1 System Summaries – Iteration 1

### 3.0.1.1 Design Description




GLAST Spacecraft Block Diagram

### 3.0.1.2 Components Summary

| Subsystem | Nominal Mass (kg) | Peak Power (w) | Avg. Power (w) | Total Mass w/ Contingency | Total Peak Power w/ Contingency | Total Avg. Power w/ Contingency |
|---|---|---|---|---|---|---|
| C&DH Total | 22 | 101 | 54 | 26 | 121 | 65 |
| ACS Total | 69 | 263 | 101 | 70 | 266 | 102 |
| Mechanical Total | 420 | 61 | 26 | 492 | 73 | 31 |
| EPS Total | 159 | 20 | 20 | 167 | 58 | 58 |
| Thermal Total | 14 | 120 | 40 | 15 | 58 | 58 |
| Communication Total | 22 | 180 | 13 | 22 | 182 | 13 |
| Spacecraft Total | 706 | 745 | 254 | 791 | 757 | 326 |
| Instrument Total | 3000 | 650 | 650 | 3000 | 780 | 780 |
| Space Segment Total | 3706 | 1395 | 904 | 3791 | 1537 | 1106 |
| DELTA 7920 Capability (28.7 deg inclination) | | | | 4545 | | |
| ARIANNE 4 Capability (5 deg inclination) | | | | 4500 | | |
| DELTA 7920 Margin | | | | 20 | | |
| ARIANNE 4 Margin | | | | 19 | | |

## 3.1 Launch Vehicle Assessment

| | |
|---|---|
| **Arianne 4** | smallest, cheapest Arianne rocket<br>$60-65M $FY96<br>Dimensions of fairing 3.6meter diameter by 4 meters high.<br>Performance: 4500 kg to 5.2 degree inclination, 600km |
| **Delta 7920** | 4445 kg to 600 km, 28.7 deg<br>6915 PAF<br>10’ fairing<br>ETR<br>$50M in $FY97 |
| **Delta III** | 5 deg inclination: 2950 kg<br>10 deg 3850 kg<br>Cost: $90-100M (direct competition w/ Atlas IIAR) |
| **Atlas IIAR** | Cost: $90-100M |

## 3.2 Orbit Analysis

### 3.2.1.1 Subsystem Overview

The GLAST orbit baseline is for a 600 km, circular orbit inclined 28.7° to the equator. Because of passages through the South Atlantic Anomaly (SAA), a lower inclination is desired. Analysis showed that changing the inclination using an on-board propulsion system is costly and will require an enormous propellant load. Lowering the inclination using the launch vehicle will result in a decreased payload mass. Therefore, all analysis will be performed assuming a 28.7° inclination. Orbit decay analysis will examine the plausibility of flying at an initial 600km altitude, while adhering to the NASA Management Instruction (NMI) on Orbital Debris Mitigation. The NMI states that after the useful lifetime of a satellite has ended, it must re-enter the atmosphere in 25 years and pose no destructive threat.

### 3.2.1.2 Subsystem Assumptions

- Launch: 2004
- Orbit: 600 km circular desired, 28.7° inclination
- Mass: 3000 kg instrument, projected 4500 kg spacecraft (maximum lift capability from launch vehicle to inclination of 28.7°)
- Area: Early projections were 15 $m^2$, current solar array design shows 19 - 20 $m^2$
- Mass/Area combinations will determine orbital decay profile.
- Orbit Determination with GPS on-board system to 300 m (1000 ft) position knowledge, GPS also satisfies timing requirement

### 3.2.1.3 Subsystem Derived Requirements

- Propulsion system: The need for propulsion can not be determined at this time.

### 3.2.1.4 Subsystem Trades Matrix

| Trade | Options (assumptions in bold) | Advantages/Disadvantages |
|---|---|---|
| Orbit Inclination | 0 - 28.7°<br>**Assumed 28.7°** | <u>Advantages:</u> eliminates need for propulsion subsystem to lower inclination, allows largest possible payload to orbit from launch vehicle, allows greater available complement of potential ground stations, eliminates partnership discussions for international launch vehicle (e.g. Arianne.)<br><u>Disadvantages</u>: lower inclinations allow for better science with smaller times in SAA. |
| Orbit Tracking | GPS vs. Ground network tracking<br>**Assumed GPS** | <u>Advantages:</u> single Subsystem able to meet orbit knowledge and timing requirements.<br><u>Disadvantages:</u> no back-up orbit determination without coherent transponder. |

### 3.2.1.5 Subsystem Analyses and Study Results

**Evaluated the following:**

**<u>Orbital Decay:</u>** The immense mass of GLAST impedes the orbital decay and results in a long lifetime – in many cases, greater than the 25 year limit. Because of the low level of the maturity of the GLAST spacecraft design, initial attempts at analyzing the orbital decay considered only the area/mass ratio of the spacecraft. Figure 3.2.1.1 shows the orbit decay profile for several mass/area ratios and considering the $+2\sigma$ flux prediction. We can see that, even for these high levels of flux, GLAST would likely violate the orbital debris NMI and most assuredly would violate the limit given nominal solar flux conditions.

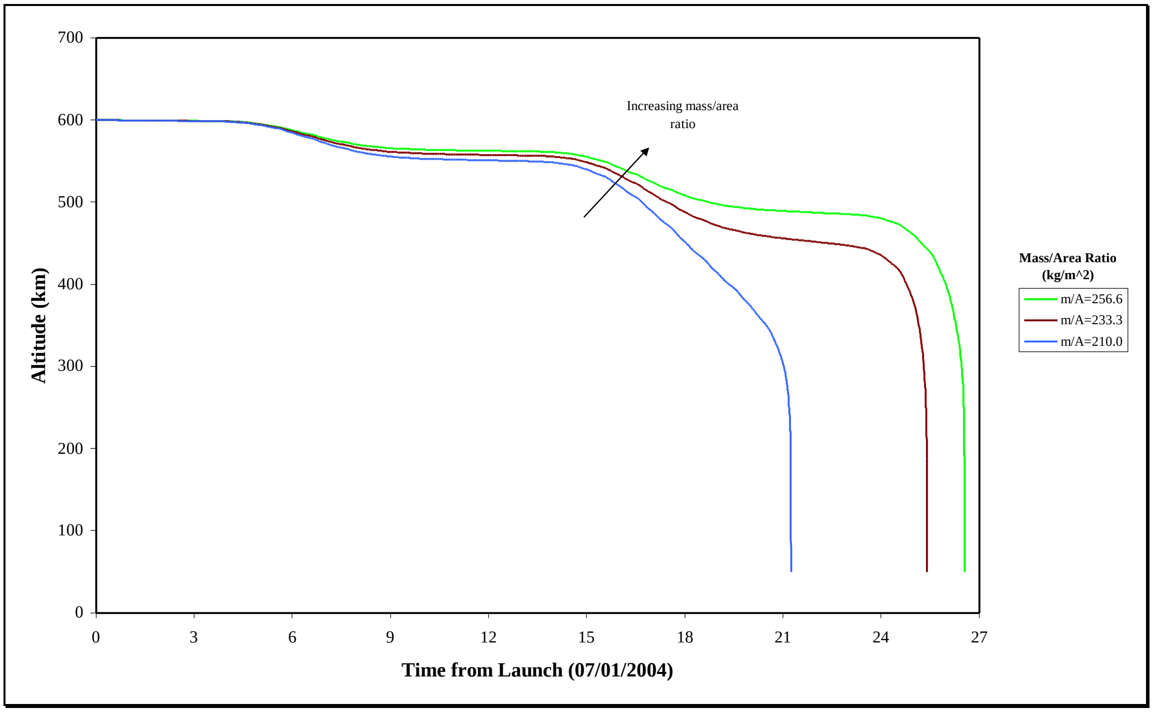



**Figure 3.2.1.1:** GLAST Orbit Decay as Function of Mass/Area Ratio

Because of the desire to fly GLAST without a propulsion system, a lower altitude may be needed to meet the 25 year NMI. Examining a mass of 4000 kg and an area of 15 $m^2$, orbit lifetimes were determined for initial altitudes of 500, 550, and 600 km and for the latest $-2\sigma$, mean, and $+2\sigma$ solar flux predictions (from 03/97) – see Figure 3.2.1.2 and 3.2.1.3.

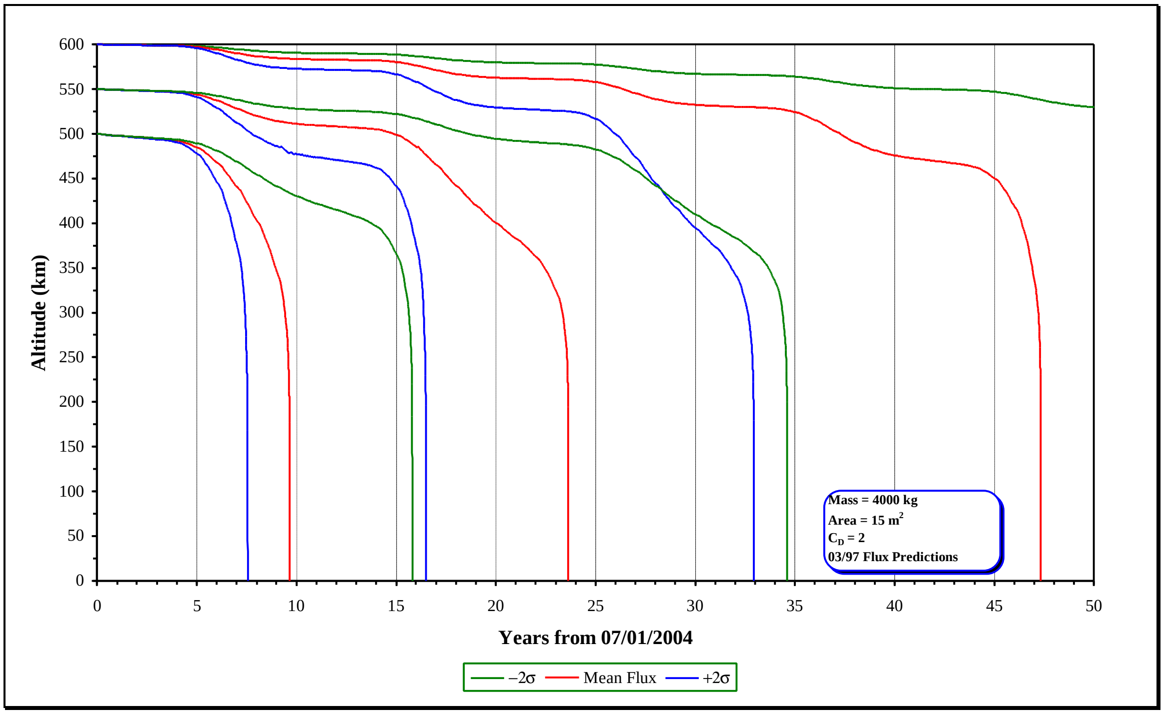



**Figure 3.2.1.2:** GLAST Orbit Decay for Various Initial Altitudes and Solar Flux Predictions

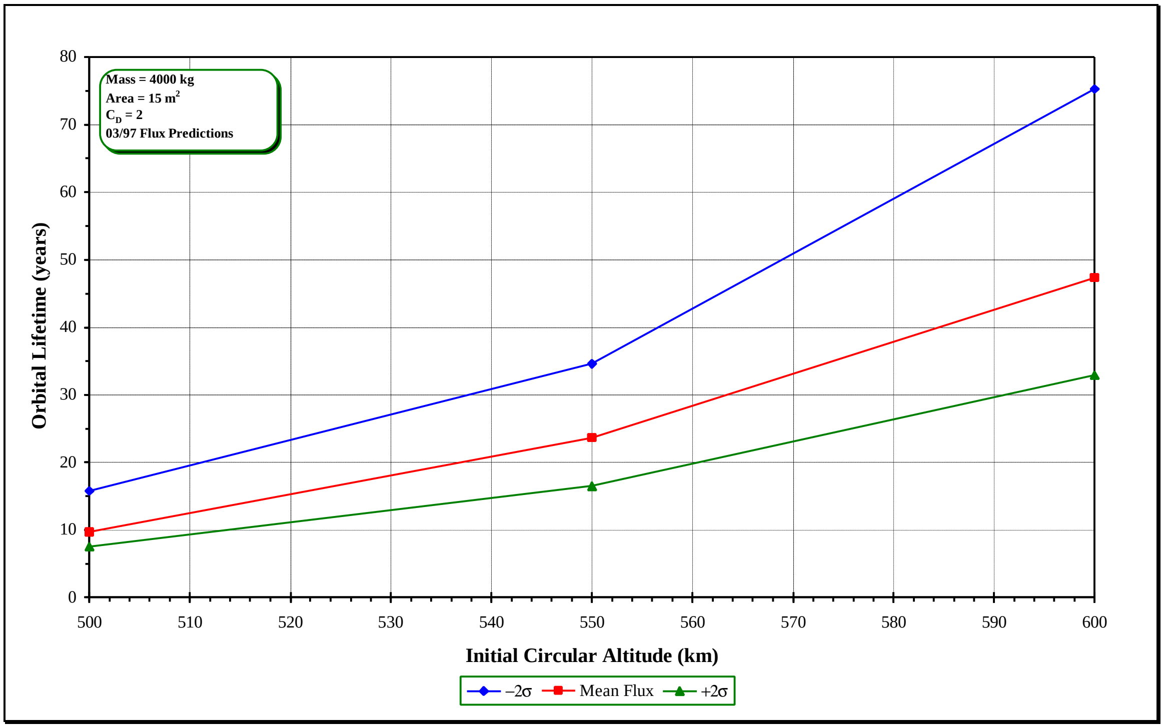



**Figure 3.2.1.3:** Potential GLAST Orbital Lifetimes

We can see that to meet the NMI and ensure that GLAST re-enters in 30 years (5 year mission plus 25 year post-operational life), the initial circular altitude should be between 500 and 550 km, assuming a mass of 4000 kg and an area of 15 $m^2$. Any change in the mass and area would affect the orbit lifetime numbers. An increase in the mass/area ratio would result in an increased lifetime while a decrease in the mass/area ratio would result in a decreased lifetime. Once the GLAST design has matured sufficiently, the lifetime analysis should be revisited.

The necessity for a propulsion system solely for re-entry is unclear at this stage in the maturity of the GLAST design. Furthermore, it is unclear whether or not GLAST would burn-up during its atmospheric re-entry – this would depend on the materials used to build GLAST and its instruments. Typically, NASA/Johnson has performed this kind of analysis.

**Station Coverage:** Ground station coverage statistics (Table 3.2.1.1) were computed using Wallops, Kourou, and Puerto Rico as candidate stations. The analysis assumed a 600 km circular orbit with an inclination of 28.7°. Further analysis would be necessary to characterize the coverage if the orbit altitude changed. The station coverage data assumed a 5° minimum elevation and all passes less than 3 minutes in length were filtered out.

| Station | Station Latitude (deg) | Passes/Day | Min. Pass (min) | Max. Pass (min) | Average Pass (min) |
|---|---|---|---|---|---|
| Kourou | 5.1 | 6.7 | 3.43 | 11.08 | 8.85 |
| Puerto Rico | 18.0 | 7.4 | 4.38 | 11.11 | 9.79 |
| Wallops | 37.9 | 4.4 | 3.48 | 9.86 | 7.94 |

**Table 3.2.1.1:** GLAST Ground Station Coverage Statistics

Furthermore, the coverage data was examined to determine ground station gap profile between successive contacts at Wallops, Kourou, and Puerto Rico (individually speaking). The gap information is important for the operations concept of downloading telemetry data. The C&DH and Communications subsystems use the data for recorder sizing and developing a download strategy with Ground Systems engineers.

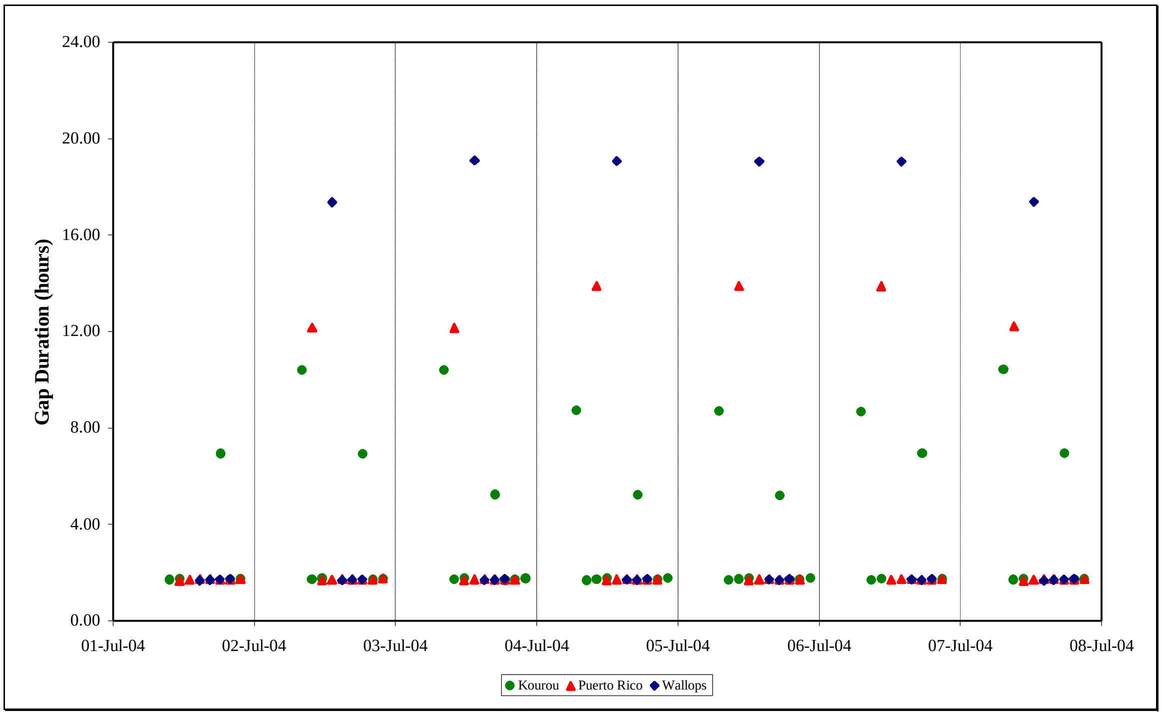



**Figure 3.2.1.4:** GLAST Ground Station Coverage Gaps

We see that the gaps between coverage vary with the ground station latitude. The bottom grouping of gap durations represent gaps of only a single orbit (i.e. station passes are on successive orbits). The longest gaps for Kourou (the lowest latitude station in this study) were from 6 – 12 hours which corresponds to gaps in coverage of from 4 – 7 orbits, respectively. Similarly, the longest Puerto Rico gaps occur over a 8 – 9 orbit span and the longest Wallops gaps occur over an 11 – 12 orbit span.

**South Atlantic Anomaly (SAA):** The SAA is a region in space over the southern Atlantic Ocean where energetic particles collect and pose a threat to the health and safety of select spacecraft instruments. Spacecraft passing through this region can experience anomalies depending on their sensitivity to certain charged particles. For GLAST, statistics (Table 3.2.1.2) were collected for passage through the SAA for altitudes of 600, 550, and 500 km. As stated previously, the SAA is truly a 3-dimensional region and the cross-sectional shape varies with altitude. Unfortunately, we do not have access to the entire model nor do we know the energy level of the particles that particularly affect GLAST. Therefore, the same SAA contour was used for all three orbit altitudes.

In Figure 3.2.1.5, we see the GLAST orbit ground (in red) highlighted in light blue when it passes through the SAA.

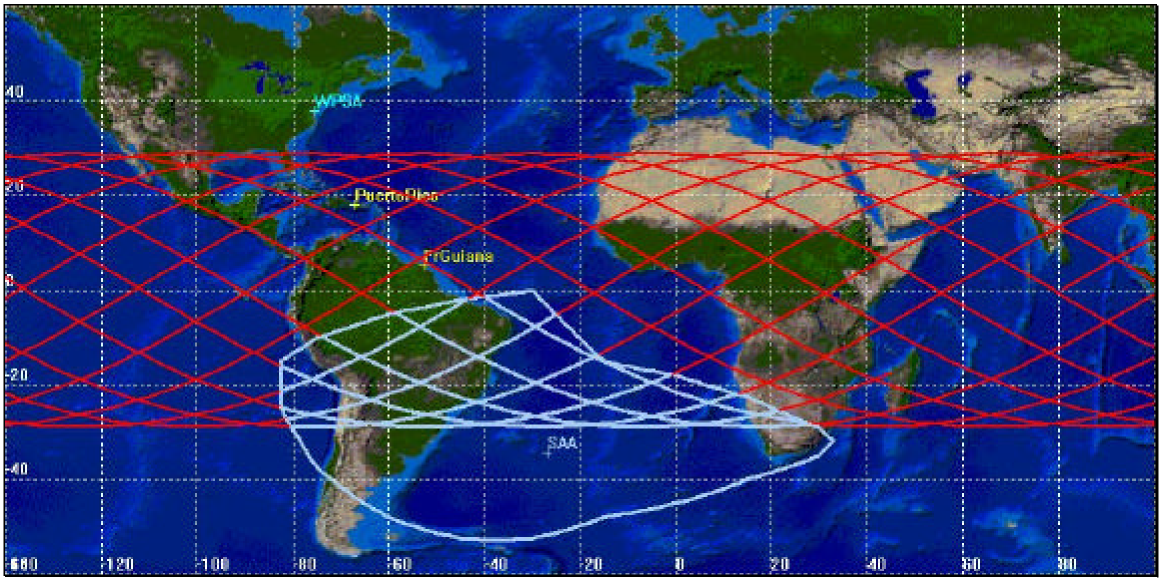



**Figure 3.2.1.5:** South Atlantic Anomaly Region

| | Altitude (km) | | |
|---|---|---|---|
| | 600 | 550 | 500 |
| Orbit Period (min) | 96.69 | 95.65 | 94.62 |
| Passes/day | 8.7 | 8.7 | 8.8 |
| Mean Duration (min) | 18.20 | 18.16 | 17.97 |
| Mean/Period (%) | 18.82% | 18.98% | 18.99% |
| Min Duration (min) | 0.75 | 1.33 | 0.06 |
| Max Duration (min) | 25.91 | 25.63 | 25.32 |

**Table 3.2.1.2:** GLAST SAA Passage Statistics

Examining the data, we see that the orbit altitude does not affect the SAA results – provided that the contour doesn't change in shape much over the different altitudes. Furthermore, the SAA passages are generally over consecutive orbits with gaps of about 11-12 hours in between 'bunches'.

# 4.0 Space Segment

## 4.1 Mechanical

### 4.1.1.0 Mechanical Design – Iteration 1

### 4.1.1.1 Mechanical Overview

The Primary structure is a built-up aluminum honeycomb 1.5m cube. The launch loads from the Payload Attachment Fitting (PAF) are carried through the four vertical corner columns of this cube to the hard points on the payload instrument. There are Shear Panels that are attached to these vertical columns. These panels become an integral load carrying part of the structure; they help take shear and torsional loads of the spacecraft and payload, plus are attachment points for the spacecraft subsystems. The Shear panels on the +Y and –Y axis will support the Solar Array Drive Assembly (SADA). The Astromast deployment assembly for the Hi-Gain Antenna will be mounted on the spacecraft Lower Mounting Deck that interfaces the PAF.

#### 4.1.1.2 Mechanical Assumptions

**Coordinate system is defined as follows:**

- X-Y plane is in the separation plane of the launch vehicle with the origin at the launch vehicle centerline.
- +Z is the launch thrust axis , X is the direction of flight, +Z is zenith
- The solar array rotates about Y-axis.

- Mass is 18% of Lift-Off weight
- Aluminum Primary Structure, 1.5 m cube
    - Honeycomb structure

**Launch vehicle will be:**

- DELTA II, 2.8m Fairing?
- DELTA II. 3m Fairing,
- 6915 Payload Attached Fitting.

- Dual wing articulated solar array 19m$^2$ total area, GaAs cells.
- Accommodate S-Band and a steerable X-Band antenna on the nadir. 4 GPS antenna.

**Spacecraft subsystem components:**

All subsystems are mounted on the Shear Panels on the spacecraft, except for the Gimbal Solar Array Control Electronic (GSACE) and Torque bars.

#### 4.1.1.3 Mechanical Derived Requirements

**Provide a platform for:**

- 3000 kg Instrument
- 3 axis control system
- 14.5-20m$^2$ solar array
- Gimbaled Hi-gain antenna
- S-band and GPS antennas
- Interface for DELTA II, 3m fairing, 6915 PAF

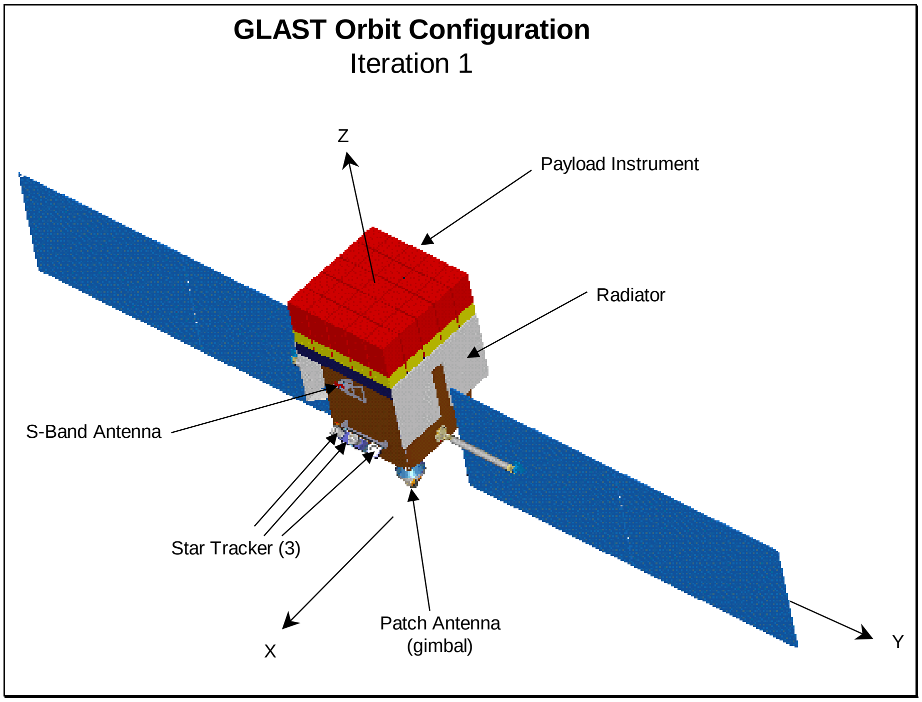
### 4.1.1.4 Mechanical Trades Matrix

| Trade | Options (selection in bold) | Advantages/Disadvantages |
|---|---|---|
| Launch Vehicle Fairing | DELTA II, 2.8m Fairing vs. **DELTA II, 3m fairing** | Advantages: DELTA II, 3m Fairing: Has more volume. Allows room for efficient packaging and stowage of solar array and growth.<br>Disadvantages: Higher cost less |
| Mechanical Size of the Solar Array | **GaAs cells** vs. Dual Junction | **Advantages: Physically smaller Array; package more efficient. Better mechanical caging to the spacecraft. Less unsupported array panel during launch.**<br>Disadvantages: More costly, technology may not nature enough for this mission. |
| Mechanical Attachment of the Star Trackers | Star Trackers Attached to Spacecraft vs**. Star Trackers Attached to Instrument** | **Advantages: Better alignment, less tolerance build-up (thermal and mechanical).**<br>Disadvantages: Need an additional structure (precision) bench, which added weight and height for the launch configuration. This current concept is getting close allowable C.G. location for the DELTAs 6915 PAF (within 25mm). |

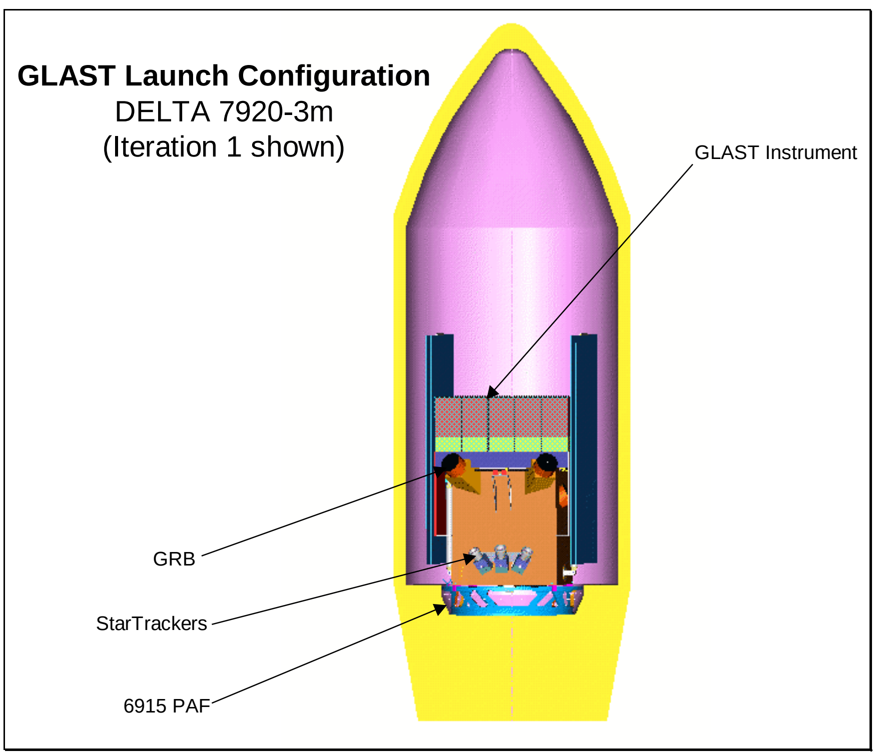
**Trades to be considered for future iterations:**

| Trade | Options (selection in bold) | Advantages/Disadvantages |
|---|---|---|
| Primary Structure | Cube Spacecraft Bus vs **Open Truss Spacecraft Bus** | **Advantages: Lower profile in a launch configuration, which lower the launch CG. More direct load path to the Payload instrument.**<br>Disadvantages: Harder to mount spacecraft subsystems, thermally not friendly. Stowing the solar array paddles will be harder to configured. |

### 4.1.1.5 Mechanical Analyses & Study Results




Orbit Configuration-Iteration 1




Launch Concept-Iteration 1

### 4.1.1.6 Mechanical Components Summary

| Element | Nominal Mass (kg) | Peak Power (w) | Avg. Power (w) | Cost ($) | Contingency (%) | Total Mass w/ Contingency | Total Peak Power w/ Contingency | Total Avg. Power w/ Contingency |
|---|---|---|---|---|---|---|---|---|
| Beam – Cylindrical Hinged | 14.6 | 0 | 0 | | 20 | 17.52 | 0 | 0 |
| Beam – Cylindrical Hinged | 14.6 | 0 | 0 | | 20 | 17.52 | 0 | 0 |
| Bracket – ACS Support | 1.0 | 0 | 0 | | 20 | 1.20 | 0 | 0 |
| Bracket – Array to Beam | 1.0 | 0 | 0 | | 20 | 1.20 | 0 | 0 |
| Bracket – Array to Beam | 1.0 | 0 | 0 | | 20 | 1.20 | 0 | 0 |
| Bracket – Star Tracker Support | 1.4 | 0 | 0 | | 20 | 1.68 | 0 | 0 |
| Deck – Bottom | 24.6 | 0 | 0 | | 20 | 29.52 | 0 | 0 |
| Gimbal – Collar | 1.1 | 0 | 0 | | 20 | 1.32 | 0 | 0 |
| Gimbal – Rotary Motor | 5.7 | 12 | 4 | | 20 | 6.84 | 14.4 | 4.8 |
| Gimbal Motor | 10.0 | 12 | 4 | | 20 | 12.00 | 14.4 | 4.8 |
| Panels | 15.7 | 0 | 0 | | 20 | 18.84 | 0 | 0 |
| Panels | 15.7 | 0 | 0 | | 20 | 18.84 | 0 | 0 |
| Panels – Array Mount | 15.7 | 0 | 0 | | 20 | 18.84 | 0 | 0 |
| Panels – Array Mount | 15.7 | 0 | 0 | | 20 | 18.84 | 0 | 0 |
| Side Panels | 25.6 | 0 | 0 | | 20 | 30.72 | 0 | 0 |
| Corners Post | 37.2 | 0 | 0 | | 20 | 44.64 | 0 | 0 |
| Reaction Wheel Pyramid | 4.4 | 0 | 0 | | 20 | 5.28 | 0 | 0 |
| Rectangular Frame L Beam | 16.2 | 0 | 0 | | 20 | 19.44 | 0 | 0 |
| SA Main Hinge | 1.2 | 0 | 0 | | 20 | 1.44 | 0 | 0 |
| SA Main Hinge | 1.2 | 0 | 0 | | 20 | 1.44 | 0 | 0 |
| SA Panel Hinge - Female | 1.4 | 0 | 0 | | 20 | 1.68 | 0 | 0 |
| SA Panel Hinge - Female | 1.4 | 0 | 0 | | 20 | 1.68 | 0 | 0 |
| SA Panel Hinge - Male | 1.6 | 0 | 0 | | 20 | 1.92 | 0 | 0 |
| SA Panel Hinge - Male | 1.6 | 0 | 0 | | 20 | 1.92 | 0 | 0 |
| SADA | 11.2 | 12 | 4 | | 20 | 13.44 | 14.4 | 4.8 |
| SADA | 11.2 | 12 | 4 | | 20 | 13.44 | 14.4 | 4.8 |
| Top Deck | 30.0 | 0 | 0 | | 20 | 36.00 | 0 | 0 |
| Gimbal Drive ("XTE" type) | 13.2 | 0 | 0 | | 15 | 15.18 | 0 | 0 |
| Astronauts Canister Assembly | 15.0 | 13 | 10 | | 20 | 18.00 | 15.6 | 12 |
| Harness | 10.2 | 0 | 0 | | 10 | 11.22 | 0 | 0 |
| Misc. structure (clips, brackets, doublers, etc) | 72.4 | 0 | 0 | | 10 | 79.60 | 0 | 0 |
| 6915 PAF (diff. of PAF 6019-6915) | 27.0 | 0 | 0 | | 10 | 29.70 | 0 | 0 |
| Mechanical Totals | 419.76 | 61 | 26 | 0 | 15% | 492.10 | 73.2 | 31.2 |

### 4.1.1.7 Mechanical New Technologies Assessment

None.

### 4.1.1.8 Mechanical Risk Assessment

**For additional mass margins, trade-off for the type of construction of the spacecraft primary structure will be:**

- Traditional build-up aluminum honeycomb, brackets, channel extrusion, clips, etc. This construction has long heritages and low risks.
- Composite material lay-up. This type of construction requires more specialized skill labor and costlier material. This construction has lots of heritage and low risks.

- The interface between Payload and Spacecraft is a standard mechanical technique and is rated as low risks. However at this point of the study it's not clear if a 3-axis kinematics mount and thermal isolation requirements between the Spacecraft and Payload is necessary.
- Due to the multi movements of the solar array drive concept, this deployment design is rated medium risks. This concept has heritage, but due to the complex mechanisms required for this deployment additional study is necessary.
- The caging technique for the Solar Array Panel during launch is considered low risk, and has lots of heritage.

### 4.1.2.0 Mechanical Design – Iteration 2

### 4.1.2.1 Mechanical Overview

Iteration 2 is the same as Iteration 1 with the following differences: the GRB module is mounted on each of the +X and the -X panels.

### 4.1.2.2 Mechanical Assumptions

Same as Iteration 1.

### 4.1.2.3 Mechanical Derived Requirements

Same as Iteration 1.

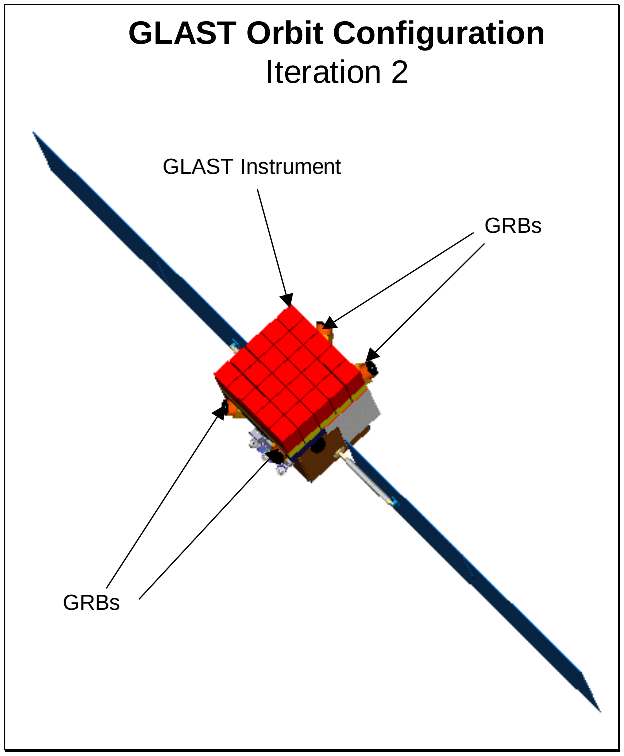
### 4.1.2.4 Mechanical Trades Matrix

Same as Iteration 1, except as noted.

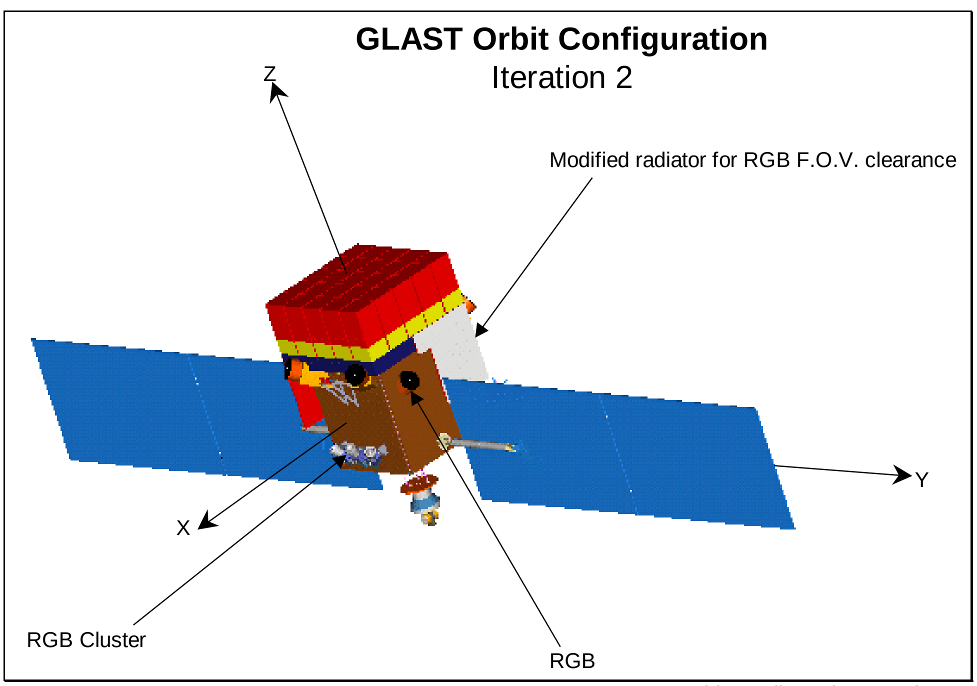
| Trade | Options (selection in bold) | Advantages/Disadvantages |
|---|---|---|
| Mechanical Attachment of the GRB Modules | GRB modules attached to Instrument Deck Vs **4 GRB modules attached to Instrument mounting deck and 2 attached to spacecraft shear panels.** | Advantages: Better distribution of FOVs and clearances with the solar array when stowed.<br><br>Disadvantages: Not a clean interface between the spacecraft and payload. The Radiator must be modified from Iteration 1 to accommodate the FOV clearances on the X-axis Shear panels. |

### 4.1.2.5 Mechanical Analyses & Study Results

The launch configuration looks the same as Iteration 1.




Orbit Configuration-Iteration 2




Orbit Configuration-Iteration 2

#### 4.1.2.6 Mechanical Components Summary

| Element | Qty | Mass per unit (kg) | Nom. Mass (kg) | Peak Power (w) | Contingency (%) | Total Mass With Contingency | Total Peak Power w/ Contingency |
|---|---|---|---|---|---|---|---|
| Beam - Cylindrical Hinged | 1 | 14.6 | 14.6 | 0 | 20 | 17.52 | 0 |
| Beam - Cylindrical Hinged | 1 | 14.6 | 14.6 | 0 | 20 | 17.52 | 0 |
| Bracket - ACS Support | 1 | 1.0 | 1.0 | 0 | 20 | 1.20 | 0 |
| Bracket - Array to Beam | 1 | 1.0 | 1.0 | 0 | 20 | 1.20 | 0 |
| Bracket - Array to Beam | 1 | 1 | 1.0 | 0 | 20 | 1.20 | 0 |
| Bracket - Star Tracker Support | 1 | 1.4 | 1.4 | 0 | 20 | 1.68 | 0 |
| Deck - Bottom | 1 | 24.6 | 24.6 | 0 | 20 | 29.52 | 0 |
| Gimbal – Collar | 1 | 1.1 | 1.1 | 0 | 20 | 1.32 | 0 |
| Gimbal - Rotary Motor | 1 | 5.7 | 5.7 | 12 | 20 | 6.84 | 14.4 |
| Gimbal Motor | 1 | 10.0 | 10.0 | 12 | 20 | 12.00 | 14.4 |
| Panels | 1 | 15.7 | 15.7 | 0 | 20 | 18.84 | 0 |
| Panels | 1 | 15.7 | 15.7 | 0 | 20 | 18.84 | 0 |
| Panels - Array Mount | 1 | 15.7 | 15.7 | 0 | 20 | 18.84 | 0 |
| Panels - Array Mount | 1 | 15.7 | 15.7 | 0 | 20 | 18.84 | 0 |
| Side Panels | 4 | 6.4 | 25.6 | 0 | 20 | 30.72 | 0 |
| Corners Post | 4 | 9.3 | 37.2 | 0 | 20 | 44.64 | 0 |
| Reaction Wheel Pyramid | 1 | 4.4 | 4.4 | 0 | 20 | 5.28 | 0 |
| Rectangular Frame L Beam | 1 | 16.2 | 16.2 | 0 | 20 | 19.44 | 0 |
| SA Main Hinge | 1 | 1.2 | 1.2 | 0 | 20 | 1.44 | 0 |
| SA Main Hinge | 1 | 1.2 | 1.2 | 0 | 20 | 1.44 | 0 |
| SA Panel Hinge - Female | 1 | 1.4 | 1.4 | 0 | 20 | 1.68 | 0 |
| SA Panel Hinge - Female | 1 | 1.4 | 1.4 | 0 | 20 | 1.68 | 0 |
| SA Panel Hinge - Male | 1 | 1.6 | 1.6 | 0 | 20 | 1.92 | 0 |
| SA Panel Hinge - Male | 1 | 1.6 | 1.6 | 0 | 20 | 1.92 | 0 |
| SADA | 1 | 11.2 | 11.2 | 12 | 20 | 13.44 | 14.4 |
| SADA | 1 | 11.2 | 11.2 | 12 | 20 | 13.44 | 14.4 |
| Top Deck | 1 | 30 | 30.0 | 0 | 20 | 36.00 | 0 |
| Gimbal Drive ("XTE" type) | 1 | 13.2 | 13.2 | 0 | 15 | 15.18 | 0 |
| Astromast Canister Assembly | 1 | 15.0 | 15.0 | 13 | 20 | 18.00 | 15.6 |
| Harness | 1 | 10.2 | 10.2 | 0 | 10 | 11.22 | 0 |
| Misc. structure (clips, brackets, doublers, etc) | | 82.0 | 82.0 | 0 | 10 | 90.20 | 0 |
| GRB Brackets | 6 | 3.0 | 18.0 | 0 | 20 | 21.60 | 0 |
| 6915 PAF (diff. of PAF 6019-6915) | 1 | 27 | 27.0 | 0 | 10 | 29.70 | 0 |
| Mechanical Totals | | 0 | 447.4 | 61 | 15% | 524.30 | 73.2 |

#### 4.1.2.7 Mechanical New Technologies Assessment

None.

#### 4.1.2.8 Mechanical Risk Assessment

The mechanical risks assessment are the same as in Iteration1 except for attachment of the GRB modules to the GLAST instrument mounting structure and the spacecraft shear panels. These mounting brackets are somewhat complex in design due to the compound mounting angles required by the GRB modules. This type construction has lots of heritage and is low risks.

## 4.2 Power & Electrical

### 4.2.1.0 Power & Electrical Design – Iteration 1

### 4.2.1.1 Power & Electrical Overview

The Electrical Power Subsystem (EPS) for the GLAST spacecraft shall be designed to support the spacecraft in all operational modes for the entire mission life. The GLAST s/c itself shall be inserted into a 600km circular orbit with a 28.5° inclination. The mission life will be 2 years with a goal of 5 years.

### 4.2.1.2 Power & Electrical Assumptions

The design is based on the following assumptions:

- DET design for reliability
- Battery technology driver: reliability after 5 years
- Maximum solar array substrate $19m^2$
- Spacecraft load: ~400 watts
- Solar Arrays will always be normal to sunline
- No shadowing on the s/a

### 4.2.1.3 Power & Electrical Derived Requirements

The derived requirements for the EPS are:

- 97 minute orbit with 35.4 minute eclipse, worse case
- Maximum DOD for $NiH_2$ is 30%; Advanced NiCd is 20%
- Orbital Average load of 1300 watts

### 4.2.1.4 Power & Electrical Trades Matrix

| Trade | Options (selection in bold) | Advantages/Disadvantages |
|---|---|---|
| Battery Technology | **SPV $NiH_2$**<br>$NiH_2$<br>Advanced NiCd | SPV $NiH_2$ selected. Mission can be accomplished with 2 $NiH_2$. Advanced NiCd would require 3 batteries. SPV is lighter weight. |
| S/A Technology | TJ-GaAs<br>GaAs | Both cells are feasible. Single Junction GaAs is marginal on 19 $m^2$. A weight vs. cost trade should be performed. |
| EPS Architecture | **DET**<br>PPT | DET selected because it is a simpler, more “reliable” design. Removal of a “series” element increases total system reliability |
| Instrument Converter Design | Single Converter<br>**Individual User Converters** | Individual converters ease I&T, ease EPS/electrical distribution design/layout. Simpler converter/more customized design as well.<br>Single module design removes converter component from instrument design (offloads this to s/c). |

### 4.2.1.5 Power & Electrical Analyses & Study Results

The main driver for the GLAST Electrical Power Subsystem (EPS) design is the 5 year mission. Due to this requirement, reliability is a prime focus and the EPS design has that as a priority.

For an orbital average load of approximately 1300 watts, the solar arrays need to be able to produce over 2860 watts end-of-life. The baselined spacecraft mechanical design can support a maximum of 19$m^2$ of solar array area within the shroud. The shroud can support this area with 2 bifold wings (i.e., 2 wings, 2 panels each). Silicon cell technology would require larger than 19$m^2$. Either GaAs/Ge or $GaInP_2$/GaAs/Ge solar cells could be used to power GLAST within the 19$m^2$ assuming the solar array is always normal to the sun and the spacecraft does not shadow the solar array. The full sun tracking is accomplished via 1) continual spacecraft rotation about spacecraft z-axis at the orbit rate and 2) seasonal rotation of solar array boom via a single axis rotary actuator for each solar array wing to correct for the beta angle.

At first approximation, GaAs/Ge solar cells would be marginal on meeting the 1300W requirement for 5 years within 19$m^2$. A detailed EOL analysis for the solar array needs to be performed including radiation, temperature, ultraviolet, thermal cycling, and assembly losses; however, the GaAs/Ge solar cells must be at least 12.4% efficient at EOL, assuming a packing factor of .9 for the 19$m^2$ area available to lay down cells. This efficiency is optimistic for a 5 year mission.

The $GaInP_2$ /GaAs/Ge solar cells would require less cell area, approximately 14.1$m^2$, assuming the same EOL losses as the GaAs/Ge cells above and less panel area, approximately 15.7$m^2$. This is simply due to the higher BOL efficiency 22% ($GaInP_2$/GaAs/Ge) vs. 18.3% (GaAs/Ge).

For a LEO spacecraft, a 5 year mission implies approximately 27,000 cycles on the battery subsystem. This is a very large number of cycles for a battery to endure and still achieve mission goals. The traditional tradeoff is that by reducing the Depth Of Discharge (DOD) on the battery (a measure of how much energy is discharged during the cycling), one increases the life of the battery subsystem. With current technology, it is likely that utilizing $NiH_2$ battery technology at a 30% DOD, one could achieve a 5 year lifetime. This works out well since with a 1300 watt load, the battery capacity required to maintain a 30% DOD is 100Amp-hours, which would be obtained by using 2 50Ahr 22cell $NiH_2$ batteries.

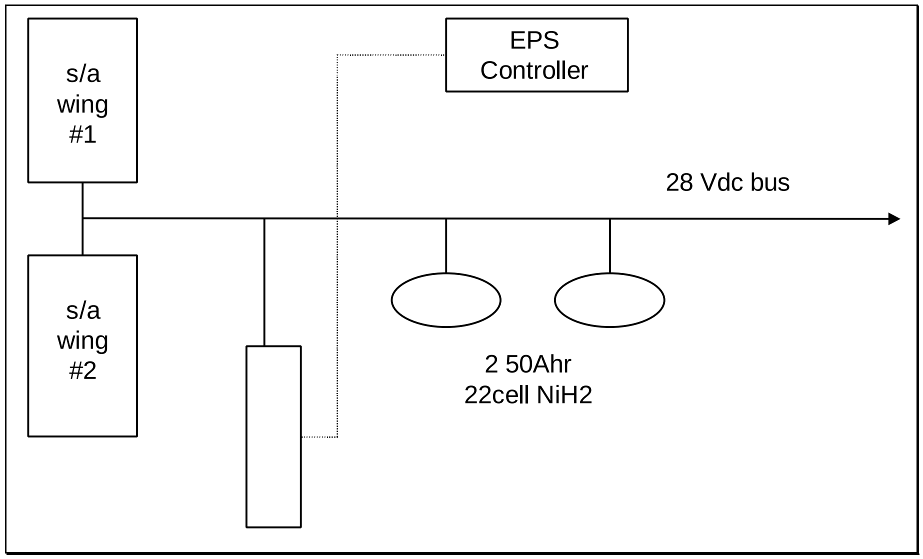
One could also consider the use of Advanced NiCd technology for the battery subsystem, but this would require a limiting DoD of 20%. This results in a design that must use 3 50Ahr, 22cell, Advanced NiCd batteries, increasing the cost, mass and volume requirements of the battery design. It's for this reason that $NiH_2$ is baselined for GLAST. (The same argument can be applied for other battery technology at this point.)

The baselined EPS design is a Direct Energy Transfer (DET) system. In this design, the solar arrays and batteries are directly tied to the spacecraft bus. Basically, the s/c bus voltage is the battery voltage that will vary from 28v ± 7volts. The advantage of this system is it's simplicity and it's efficiency. It is also extremely reliable, utilizing shunts to dissipate excess power. A Peak Power Tracking (PPT) system, such as one used on GRO, introduces a series element in the s/a power path. Although this allows for the s/a to be operated at it's peak-power point, there is an efficiency hit due to the inherent conversion. There is also a reliability concern in having a series element in the power path. At this point, there is no guiding reason to utilize a PPT system and very good reasons for a DET. For efficiency reasons, a regulated spacecraft bus (i.e., one that operates at 28v ± 1% or so) does not make sense and is not baselined.

The EPS will provide an unregulated 28±7Vdc power bus. It was assumed for this study that each user, including the instrument, would provide its own power converter, if required, and include that power consumption within their budget. No single box was designated for power conditioning and distribution. Once details are obtained about how many and what type of power services are required, a detailed trade can be performed to determine which system may be more efficient in terms of power, mass, and thermal loading. To a first order, assuming that each user will have different voltage requirements and input impedances, using individual converters offers the following advantages:

- Lower Distribution Losses: Harness loss for a 20W, 5V user where the converter is 1ohm from the user has a harness loss of $(4A)^2$ (1ohm)=16W; Harness loss for a 20W, 5V user where the converter is at the user has a harness loss of $(20W/28V)^2$ (1ohm)=.51W.
- Elimination for post regulation at the user end.
- Optimal designs for each user: Each converter can be operated at the peak load where it is more efficient. A single converter has to be designed for maximum load but many of the users will not be operated at maximum load and will therefore have low efficiency.
- Isolated Grounding for each user reducing noise and interference.
- Greater Reliability in that a single converter failure will effect only one user rather than potentially more than one user.
- Easier I&T for the users by providing the simplest spacecraft to instrument interface (low impedance 28±7Vdc) to simulate for testing.

The GLAST EPS is designed to provide an orbital average load of 1300 watts for a 5 year mission. To achieve this goal, the EPS will utilize either a $19m^2$ GaAs/Ge solar array or a $15.7m^2$ $GaInP_2$/GaAs/Ge solar array, 2 50Ahr 22cell $NiH_2$ batteries and a DET architecture. The solar arrays will be tracking. The EPS will be able to handle loss of one battery cell and/or one solar array string with no compromise of s/c performance.




EPS Block Diagram 1

### 4.2.1.6 Power & Electrical Components Summary

| Element | Make/Model | Qty | Cost ($) | Contin-gency (%) | Total Mass w/ Contingency | Total Peak Power w/ Contigency | Total Avg.Power w/ Contigency | Comments |
|---|---|---|---|---|---|---|---|---|
| Solar Array | GaAs 19m2<br>TJ GaAs 15.7m2 | 1 | $7,315,000<br>$7,865,700 | TBD | TBD | 0 | 0 | 2 Wings, 2 Panels Per Wing, SA Boom Parallel To S/C Y Axis |
| Battery | SPV NiH2 50Ahr 22 cells | 2 | $450,000 | 20 | 73kg | 0 | 0 | |
| EPS PDCU | DET (MAP-like) w/modification | 1 | $850,000 | 20 | 18kg | 34 | 34 | |
| Harness | Estimate | | TBD | 5 | 22.05 | 0 | 0 | |

**Solar Array**

The EPS shall utilize either single junction GaAs cells resulting in a $19m^2$ array or TJ-GaAs cell technology, resulting in a $15.7m^2$ total array size.

**Battery**

The EPS shall utilize 2, Single Pressure Vessel (SPV) 22cell 50Ahr $NiH_2$ batteries.

#### 4.2.1.6.3 Power Distribution and Control Unit

The EPS shall utilize a PDCU that is based on the MAP-PSE design. It will perform all EPS control including battery charge control and commanding. Redesign of the PSDU with be required to handle the higher power requirements.

### 4.2.1.7 Power & Electrical New Technologies Assessment

Triple Junction GaAs cells are a relatively new technology, but they have been flown on some Commercial spacecraft with good results. Additionally, the GSFC TRACE spacecraft has a small dual junction GaAs "test panel" on the main solar array panel. This selection imposes no additional risk to the s/c.

### 4.2.1.8 Power & Electrical Risk Assessment

The EPS design is heritage both in concept and components. Risk is very low.

## 4.3 Propulsion

The NASA guidelines governing orbital debris (NSS 1740.14) are not absolute requirements. NASA HQ has stated clearly that these guidelines must be balanced against program cost, schedule, and other constraints. Consequently, it is unlikely that HQ would require the inclusion of a propulsion subsystem on a spacecraft solely for the purpose of end-of-life disposal. The resultant impacts to safety, available volume, thermal, etc. are very significant.

The IMDC study for GLAST demonstrates that the mission requirements can be met without a propulsion subsystem. Therefore, a propulsion study is not included in this final report.

## 4.4 Guidance, Navigation & Control

### 4.4.1.0 Guidance, Navigation & Control Design – Iteration 1

### 4.4.1.1 Guidance, Navigation & Control Overview

The GLAST spacecraft will be placed in a circular orbit at 600 km altitude and 28.5 degree inclination by a Delta ELV. GLAST has a mission life requirement of two years with a goal of five years. There are two science data gathering modes. During the first one or two years of the mission, the spacecraft will perform an all-sky survey. It is desired to scan the entire celestial sphere uniformly every 60 days or so during this mission phase. During the latter part of the mission, the spacecraft will stare at selected targets. To avoid occultation by the earth, it is desirable to slew the spacecraft between a primary and a secondary target every orbit. The pointing accuracy requirement for all science modes is only about five degrees. The knowledge requirement, however, is: 10 arc seconds standard deviation (i.e., $1\sigma$), end-to-end. These aspects of the mission are very much like previous Goddard missions such as GRO, XTE, and EUVE, so we can make use of our experience base. In particular, we use star trackers and gyros for attitude knowledge and reaction wheels for attitude control. Wheel angular momentum buildup is counteracted by magnetic torquers, which require no expendables.

A novel aspect of GLAST is a rapid repointing requirement when a gamma ray burst is observed. If a burst is observed in GLAST's "peripheral vision," which extends approximately 80 degrees off the instrument boresight, it is desired to slew the spacecraft so that the burst is in the instrument's 30 degree "sweet spot" within 5 to 10 minutes. The instrument may also be required to slew to externally-detected bursts, but this response does not have to be as rapid.

There is also a precise timing requirement of 1µsec on time-tagging measurements.

### 4.4.1.2 Guidance, Navigation & Control Assumptions

The precise pointing knowledge of 10 arc seconds is only required in the 30 degree (half cone angle) "sweet spot" of the instrument. Pointing accuracy requirements can be relaxed to (TBD) over the rest of the 80 degree (half cone angle) field of view.

It is assumed that the instrument boresight will not be pointed below the local horizontal in either the survey or staring mode, except possibly for observation of a gamma ray burst, and that communication through the high-gain antenna will not be required while the instrument boresight is pointed below the local horizontal in any case. It is also assumed that the high-gain antenna is gimballed to provide full coverage of the hemisphere opposite to the instrument boresight. Thus repointing of the spacecraft for communications is not required.

GLAST has no sun or moon avoidance constraints. The instrument will not be damaged by pointing at the earth, but gamma-ray background from the earth's limb makes an earth pointing attitude undesirable. Thus the rapid repointing slews for gamma ray bursts can be the most direct (eigenaxis) slews.

At deployment, attitude rates (tip off rates) of no more than 1.5 degrees per second will be imparted to GLAST by the Delta ELV. The 100 Ampere-hour battery capacity requires that the ACS despin the spacecraft and acquire a sun-pointing attitude in less than two hours.

The spacecraft principal moments of inertia are assumed to be 1800 kg-$m^2$ around the instrument boresight and 1500 kg-$m^2$ around the axes perpendicular to the instrument boresight. The solar array area is assumed to be 20 $m^2$, and the offset between the spacecraft center-of-mass and center-of-pressure to be 1.5 meters. These values, which were obtained from the mechanical model developed in the IMDC, are used to estimate environmental torques, and thus to specify the actuator sizing.

#### 4.4.1.3 Guidance, Navigation & Control Derived Requirements

The end-to-end attitude knowledge requirement results in derived requirements for ACS performance and alignment of the gyro/star tracker navigation base to the instrument. It is assumed that the alignment can be calibrated using known gamma-ray point sources. However, the alignment must be stable or modelable to 5 arc seconds. This places severe restrictions on allowable thermal distortions. In particular, thermal control of the star trackers, which must be on the outside of the spacecraft, must be carefully thought out. The trackers should be mounted as close as possible to the instrument grid to minimize alignment shifts.

The derived requirement for attitude determination of the navigation base is 5 arc seconds. This requires precise star trackers and moderately precise gyros. At least two star trackers are required, since a single tracker cannot determine a rotation angle about its boresight to this accuracy.

The all-sky survey mode requires off-zenith pointing, since otherwise the coverage of the polar regions is unsatisfactory. The pointing strategy is TBD, but it will require a rocking motion of the instrument boresight above and below the orbit plane. The regression of the ascending node due to earth oblateness is 6.4 degrees/day in the GLAST orbit, so the orbit normal vector rotates 360 degrees in less than 60 days. The rocking motion may have a period of about the orbit period, or it may be more like a month. If this motion has an amplitude greater than 30 degrees, there will be some incursion of the earth's limb into the instrument field of view.

The ACS is required to point the normal vectors to the solar arrays to within 5 degrees of the sun during normal science modes whenever the spacecraft is in daylight. A sun-pointing safemode is required in case of an ACS anomaly. We assume that the instrument boresight is anti-sun pointing in this safe mode. With this orientation, the solar array gimbals are commanded to their deployment configuration for safehold, and the normal vectors must be moved to within 20 degrees of the sun within TBD minutes and maintained in this orientation whenever the spacecraft is in daylight.

The acquisition mode will use reaction wheels to despin and point the spacecraft if the initial angular momentum is small enough to be absorbed by the reaction wheels. If the initial angular momentum exceeds this limit, the magnetic torquers will be used to reduce it to an acceptable level. The gyro will provide angular rate information during acquisition, with the magnetometer available as backup, and coarse sun sensor data will be used to orient the spacecraft toward the sun. The star trackers can provide attitude and rate information when the angular rates have been reduce to 0.25 degrees/sec.

The precise timing requirement can only be provided by use of the Global Positioning System (GPS). Raw GPS data will provide spacecraft position to about 100 meters and time to 1μsec, but this requires contact with 4 GPS spacecraft at all times. An alternate strategy is to use dynamically-aided GPS, such as the GEODE system being developed by the Flight Dynamics Analysis Branch and the Guidance, Navigation, and Control Branch. This can cope with GPS contact outages of TBD minutes, during which time only one GPS contact is required. It also yields a more precise position determination, which is not needed for GLAST, however.

### 4.4.1.4 Guidance, Navigation & Control Trades Matrix

A general trade that covers all components is an implicit redundancy requirement driven by the five-year mission life goal. Thus we have specified four for three redundancy of reaction wheels and three for two redundancy of star trackers. Other components (Attitude Control Electronics, gyro, coarse sun sensors, magnetometers, and GPS receivers) are doubly redundant. Only one set of three orthogonal torquers is use, but each torque rod has redundant windings.

**Subsystem level trades completed for Iteration 1**

| Trade | Options (selection in bold) | Advantages/Disadvantages |
| --- | --- | --- |
| Number of Wheels | three | Advantages: less power, weight, cost<br>Disadvantages: no redundancy |
| | **four** | Advantages: single wheel failure tolerable<br>Disadvantages: more power, weight, cost |
| Reference Sensors for Science Mode | star tracker only | Advantages: simplest<br>Disadvantages: limited slew rate capability |
| | **gyro/star tracker** | Advantages: most accurate; permits higher slew rates<br>Disadvantages: most expensive |
| Wheel Type | Ithaco E-wheel | Advantages: XTE experience fast acquisition<br>Disadvantages: power, weight |
| | Honeywell HR150 | Advantages: most torque; most momentum capacity<br>Disadvantages: cost, weight, power |
| | **Ithaco B-wheel** | Advantages: less power & weight<br>Disadvantages: slower acquisition |

**Trades to be considered for future iterations Subsystem Level**

| Trade | Options | Advantages/Disadvantages |
| --- | --- | --- |
| GPS mode | raw GPS | Advantages: simplicity<br>Disadvantages: requires contact with 4 GPS |
| | GEODE | Advantages: can cope with limited outages<br>Disadvantages: software complexity |

**Trades to be considered for future iterations System Level**

| Trade | Options | Advantages/Disadvantages |
|---|---|---|
| Science Downlink Mode | point-and-dump | Advantages: mechanical simplicity<br>Disadvantages: 2% loss of science |
| | deployed, gimballed high gain antenna | Advantages: no science interruption<br>Disadvantages: cost, weight, complexity |

Analyses were performed to determine pointing knowledge, actuator sizing requirements, and acquisition times. All these order-of-magnitude analyses should be verified by detailed simulations in Phase A.

The Lockheed-Martin Autonomous Star Tracker (AST-201) has systematic errors of 2.3 arc seconds in the determination of the tracker boresight direction, and 21 arc seconds for rotations about the boresight. These include alignment errors and variation over temperature. The measurement noise equivalent angles are 1.5 arc seconds in the determination of the tracker boresight direction, and 24 arc seconds for rotations about the boresight.

For GLAST, we will use two AST-201s with orthogonal boresights, which yields systematic errors of 2.3 arc seconds in the plane of the tracker boresights and 1.6 arc seconds perpendicular to this plane, and noise equivalent angles of 1.5 arc seconds in the plane of the tracker boresights and 1.1 arc seconds perpendicular to this plane. All these numbers are quoted as standard deviations (i.e., 1$\sigma$ estimates). The performance perpendicular to the plane of the boresights is a result of combining two independent tracker measurements with equal errors. Adding the systematic errors and the noise equivalent angles gives worst-case errors of 3.8 arc seconds, which is within the 5 arc seconds budgeted. Use of gyro data can reduce the noise errors, but not the systematic errors. Constant or near-constant systematic errors can be removed by calibrating against known sources, as noted above.

The tracker orientations are chosen so that they will not experience sun or earth interference during the baseline mission. Sun impingement in a tracker field-of-view will result in temporary blindness, but not in permanent damage to the tracker. A third tracker is provided for redundancy.

**Reaction Wheel Sizing**

The sizing of the reaction wheels is driven by the rapid repointing requirement. If the slews are torque-limited, full acceleration will be applied for the first half of the slew and full deceleration for the second half. The resulting slew time is given by `t=SQRT(4θ/α)` where θ is the slew angle and `α=(wheel torque)/(moment of inertia)` is the angular acceleration. We consider a slew of 60 degrees or *p*/3 radians, as is required for rapid repointing. The slew time for a transverse moment of inertia of 1500 kg-m$^2$ and a wheel torque of 0.04Nm is about 396 sec, or 6.6 minutes. This torque is available with the Ithaco Type B T-WHEEL, which has been employed on the TOMS spacecraft. This wheel has an angular momentum capacity of 19.5Nms. The momentum change of the wheel during the 396 sec slew is (1/2)x(396 sec)x(0.04Nm), which is less than 8Nms, so this slew is definitely torque-limited, rather than rate limited. The maximum rate during the slew is only 0.3 deg/sec.

If we consider a 180 degree slew, as may be required by an external trigger, the slew time, angular momentum change, and maximum rate will all be $\sqrt{3}$ times these values, assuming that this longer slew is also torque-limited. This gives a time of about 11.5 minutes, angular momentum change of less than 14Nms, and maximum rate of about 0.5 deg/sec. Thus this slew will be torque-limited unless the wheel was storing a significant angular momentum in an unfavorable direction at the beginning of the slew.

For redundancy, we will use four wheels in a pyramid configuration. Thus the torque available on any axis will be greater than the torque of a single wheel, and the above estimates are conservative. In case of a single wheel failure, it will still be possible to slew about any axis, although performance may be reduced.

Larger wheels would permit faster slews, but would be heavier and more expensive and would require more power. A higher-torque version of the Ithaco B-wheel is under development; this would have about the same mass, but, the peak power would be higher if full torque were applied.

**Magnetic Torquer Sizing**

The sizing of the magnetic torquers is driven by the expected environmental torques. Three sources of environmental torques were analyzed: gravity gradient, solar radiation pressure, and aerodynamic.

The order of magnitude of the gravity gradient torque is $w_0^2 \Delta I$, where $w_0$ is the orbit rate, approximately $10^{-3}$ radians/sec, and $\Delta I$ is the difference between the largest and smallest principal moments of inertia, 300 kg-m$^2$. This gives a gravity-gradient torque of 300μNm. This is a very small value, due to the near-equality of the spacecraft moments of inertia.

Both the solar radiation pressure torque and the aerodynamic torque are the product of a pressure, an area, and the offset between the center-of-mass and the center-of-pressure. For GLAST, the product of the area and the offset between the center-of-mass and the center-of-pressure is 20m$^2$ times 1.5m, or 30m$^3$. The solar radiation pressure is 4.4μN/m$^2$, so the solar radiation pressure torque is estimated to be 132μNm. The solar radiation pressure torque is generally negligible in near-earth orbits.

The pressure to be used in the aerodynamic torque computation is the dynamic pressure $rv^2$, where ρ is the atmospheric density and $v$ is the spacecraft velocity, approximately 7 km/sec in near earth orbit. The density is highly variable, depending on solar activity. A worst-case estimate at 600km altitude is $4 \times 10^{-12}$kg/m$^3$. Although this is highly unlikely to be encountered during the GLAST mission, a conservative analysis sizes the torquers for this case. This gives a dynamic pressure of 200μN/m$^2$, and thus an aerodynamic torque estimate of 0.006Nm.

It is easily seen that aerodynamic torque is the dominant environmental torque. The torquers are sized by requiring the product of their magnetic moment and the ambient magnetic field strength to be equal to the environmental torque, so that the torquers can compensate for this torque, on average. The reaction wheels can absorb periodic components of the torque and control the spacecraft when it is in a position of unfavorable magnetic field orientation. Taking the average magnetic field strength at 600km altitude to be 25μT gives a torquer requirement of 240Am$^2$. Thus 300Am$^2$ torque rods have been specified on each axis. This is the size of the torquers used on XTE and TRMM.

**Acquisition Times**

The torquer size determines the acquisition time for tipoff rates that exceed those that can be stored in the reaction wheels. The maximum tipoff rate of 1.5 deg/sec = 0.026 rad/sec about a transverse axis with moment-of-inertia equal to 1500 kg-m$^2$ give an angular momentum of 40Nms. The available magnetic torque is on the order of the product of the dipole strength and the magnetic field strength, or $7.5 \times 10^{-3}$Nm. This torque can remove about 40Nms of angular momentum in 1.5 hours, or one orbit. This estimate is approximate, since the actual value will depend on the varying alignment of the magnetic field to the angular momentum. Not all the angular momentum needs to be removed magnetically, however, since some can be stored in the wheels. It is reasonable to store as much as 10Nms in each wheel while maintaining torque authority to slew the spacecraft to orient the solar array normals to the sun. The absorption of this residual momentum into the wheels and pointing the arrays to the sun requires about 10 to 20 minutes.

### 4.4.1.6 Guidance, Navigation & Control Components Summary

| Element | Make/ Model | # | Nominal Mass (kg) | Peak Power (w) | Avg. Power (w) | Cost ($K) | Contingency (%) | Total Mass w/ Contingency | Total Peak Power w/ Contigency | Total Avg. Power w/ Contigency |
|---|---|---|---|---|---|---|---|---|---|---|
| Star Tracker | LM AST201 | 3 | 15 | 36 | 36 | 1800 | 1 | 15.15 | 36.36 | 36.36 |
| Inertial Reference Unit | Honeywell MIMU | 2 | 6.8 | 14.8 | 14.8 | 500 | 1 | 6.868 | 14.948 | 14.948 |
| Coarse Sun Sensor Eyes | Adcole 11866 | 12 | 0.06 | 0 | 0 | 30 | 1 | 0.0606 | 0 | 0 |
| Reaction Wheels | Ithaco Type B | 4 | 20.4 | 180 | 28 | 675 | 1 | 20.604 | 181.8 | 28.28 |
| Reaction Wheel Driver | Ithaco Type B | 4 | 3.6 | | | | 1 | 3.636 | | |
| Torquer Bars | Ithaco TR300UPR | 3 | 16.8 | 18.9 | 9 | 250 | 1 | 16.968 | 19.089 | 9.09 |
| Magnetometer | Ithaco M-203 | 2 | 2 | 4 | 4 | 50 | 1 | 2.02 | 4.04 | 4.04 |
| GPS Receiver | Motorola Viceroy | 2 | 3 | 9.6 | 9.6 | 500 | 1 | 3.03 | 9.696 | 9.696 |
| GPS Antenna | Motorola patch | 4 | 1.4 | 0 | 0 | | 1 | 1.414 | 0 | 0 |
| | | | 0 | 0 | 0 | | | 0 | 0 | 0 |
| **ACS Totals** | | | **69.06** | **263.3** | **101.4** | **3805** | | **69.7506** | **265.933** | **102.414** |

### 4.4.1.7 Guidance, Navigation & Control New Technologies Assessment

No new ACS technologies have been identified as useful for the GLAST mission.

### 4.4.1.8 Guidance, Navigation & Control Risk Assessment

This is a “standard” mission, very much like GRO, XTE, and EUVE. All the selected ACS components will have flight experience before the development of GLAST. Growth of the spacecraft moment of inertia or solar array area may require resizing of some of the components, which may adversely impact the spacecraft power and weight budgets. Detailed simulations are required to verify the adequacy of the selected components, but they were selected to provide sufficient margins.

## 4.5 Communications

This section of the report covers the GLAST spacecraft communications subsystem concept developed in the IMDC. This concept includes one possible way to satisfy the GLAST mission requirements and there could be many other ways to achieve this goal. The communications subsystem concept includes assumptions, derived requirements, trades matrix, block diagram and component summary, new technology assessment and risk assessment. It does not include a detailed cost analysis. Furthermore, there are a number of issues and open items that remain. Resolution of these issues requires further study from the GLAST project. These issues are clearly listed and explained in detail.

### 4.5.1.0 Communications Design – Iteration 1

### 4.5.1.1 Communications Overview

**S-Band System:**

- Fourth Generation TDRSS Transponder
- 2 Omni Antennas to provide near spherical coverage
- RF Output Power: 5 watts at transponder
- Receives Command Uplink from ground or TDRSS
- Passes command information to C&DH subsystem
- Receives alert and housekeeping information from C&DH subsystem
- Transmits alert signal to TDRSS
- Transmits housekeeping information to ground
- C&DH subsystem commands transponder between GN and TDRSS modes as necessary

**X-Band System:**

- Receives the science data from the C&DH subsystem
- Transmits the science data to the ground
- Has a transmitter and a medium gain antenna

**Communications Issues**

Requirement to have alert signal sent to ground within seconds drives the use of TDRSS. Cost and operations impact.

Assuming the S-band link to TDRSS can support a 1 kbps data rate for alert signal.

Assumed a medium gain 4-element patch antenna on X-band downlink. Implies that S/C will gimbal antenna for downlink. Gimbal combined with beamwidth of antenna will allow for a 290-degree coverage about S/C. However, the solar arrays may physically block the antenna signal from reaching the Earth depending on the orientation of the spacecraft. In this situation, several options may be considered: slewing the spacecraft, missing a pass and rescheduling at another time, or storing data onboard until next pass. Slewing spacecraft will result in ~30 minutes loss of science observation time.

Ground site verification of S and X-band compatibility.

The transponder can support 16 kbps receive for flight software update, but only in TDRSS mode. When the transponder is in STDN mode, it can receive 2 kbps. Therefore, GLAST must use TDRSS to perform the flight software update. The TDRSS MA mode must be used to support the return alert signal. However, the TDRSS forward link on an MA channel is approximately 10 dB lower than that on a SSA channel. The link analysis indicates that the system can support a 4 kbps data rate through a TDRSS SSA channel.

The current requirement is for the alert signal to be transmitted via TDRSS only. Since the transponder has to be in either GN mode or TDRSS mode, the spacecraft will not be able to transmit the alert signal when it is in contact with the ground station. The Project elected to ignore the alert signal if this situation arises. Another option would be to direct the alert signal to the ground station as well.

#### 4.5.1.2 Communications Assumptions

| | |
|---|---|
| Maximum Altitude: | 600 Km (low inclination, circular orbit) |
| Data Volume: | 34 Gbits/day (see C&DH analysis) |
| Ground Station Contacts/day: | 1 |
| Time of each contact: | 9 min. (8-min. data transmission) |
| Total contact time/day: | 9 min. |
| TDRSS channel for alert signal | |
| S/C housekeeping data rate: | 2 kbps continuous |
| Downlink Data Rate Required: | X-Band: 68 Mbps (see C&DH analysis)<br>S-Band: 400 kbps (see C&DH analysis) |
| Return Frequency: | X-Band: science data S-band: alert signal (TDRSS only) and housekeeping |
| Forward Frequency: | S-Band (commanding from GN) |
| Uplink Data Rate: | 2 Kbps (4 kbps via TDRSS for flight software update, originally talked about 16 kbps but system becomes more complex to support 16 kbps) |
| BER: | 10E-6 (TDRSS only guarantees 10E-5, alert signal only) |
| R-S Coding on X-Band channel | |
| Coherent Transponder: | TDRSS transponder required for alert signal, not using coherent tracking/ranging, using GPS |
| Ground station dish size: | 5 m for S-Band uplink, X-Band downlink, and S-Band housekeeping downlink |
| Redundancy: | Yes |
| Mission Lifetime: | 5 years |

Communications Assumptions

#### 4.5.1.3 Communications Derived Requirements

I. Subsystem: Spacecraft Communications

II. Functional Category:

A. Spacecraft Communications Subsystem

1. Data Transmission
    a. transmit at allocated frequencies.
    b. transmit science data at 68Mbps bit rate on X-Band to ground station.
    c. transmit housekeeping telemetry at 400 kbps on S-Band to ground station.
    d. transmit alert signal at 1 kbps on S-Band through TDRSS MA channel.
    e. transmit 34 Gbits of data/day (inclusive of instrument & S/C).
    f. transmit S-Band signals (alert and housekeeping) w/ spherical coverage.
    g. transmit X-Band downlink on gimbaled medium gain antenna.
    h. CCSDS compliant.
    i. a 3 dB minimum margin on the link budget.
    j. do not interfere w/science observations.
2. Command Reception
    a. receive at allocated S-Band frequency.
    b. receive in GN mode at 2 kbps bit rate (4 kbps via TDRSS for flight software update).
    c. receive w/ spherical coverage.
    d. CCSDS compliant.
    e. a 3 dB minimum margin on the link budget.
    f. BER 10E-6 (only 10E-5 guaranteed through TDRSS).

III. Performance Specifications:

A. Spacecraft Communications Subsystem

1. Data Transmission

   a. Transmit at allocated frequency with TBD modulation, TBD polarization, frequency, etc.

   b. transmit X-Band at 64Mbps rate at 46dBm (EIRP) for a total contact time of 8 min. per day (includes Reed-Solomon overhead).

   c. transmit 34 Gbits/day.

   d. transmit X-Band via medium gain 4-element, gimbaled, patch antenna.

   e. Transmit S-Band at 400kbps rate at 31dBm (EIRP) for a total contact time of 8 min. per day.

   f. transmit S-band via 2 opposed omni-antennas providing near spherical coverage.

   g. CCSDS compliant.

2. Command Reception

   a. Receive at S-band with TBD modulation, polarization, frequency, etc.

   b. receive at 2kbps rate (4 kbps via TDRSS for flight software update).

   c. receive via S-band w/2 opposed omni-antennas providing near spherical coverage.

   d. CCSDS compliant.

### 4.5.1.4 Communications Trades Matrix

**Subsystem trades completed for Iteration 1**

| Trade | Options (selection in bold) | Advantages/Disadvantages |
|---|---|---|
| Science Downlink Frequency | S-Band vs. **X-Band** | Advantages: X-Band transmitters available w/broader bandwidth (up to 150MHZ). Ground stations available to support X-Band return link. GLAST data rate requires wider spectrum than S-Band spectrum allocations can support<br>Disadvantages: None identified |
| Housekeeping Downlink Frequency | **S-Band** vs. X-Band | Advantages: S-Band system has omni antennas with near spherical coverage allowing the spacecraft to transmit health and safety information during safe-hold and spacecraft emergencies with loss of attitude control. Hardware is already on spacecraft. Link budgets support additional bandwidth required.<br>Disadvantages: Requires slightly more power (~30 watts, 8 minutes every day). Requires ground station to support both S-Band and X-Band simultaneous downlinks (which is readily available). |
| Housekeeping Link Network | **Ground** vs. TDRSS | Advantages: The ground station is more cost effective than TDRSS, since the ground station is already being used to receive telemetry. Many ground stations available to support S-Band downlink.<br>Disadvantages: Not as easy to schedule. Spacecraft has to be over a ground station. |

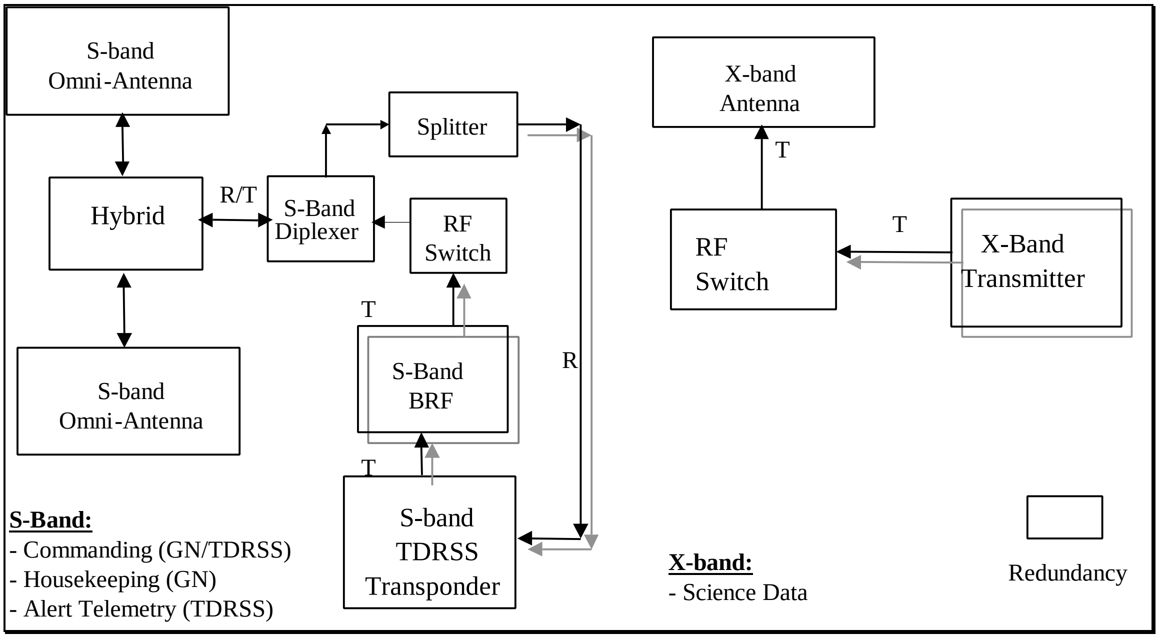
**Subsystem Trades Completed for Iteration 1 (Continued)**

| Trade | Options (selection in bold) | Advantages/Disadvantages |
|---|---|---|
| Data Compression | Yes vs. **No** | Advantages: Will reduce amount of spacecraft downlink time. Store more onboard data. Downlink more data.<br>Disadvantages: Potential loss of data depending on algorithm used (Lossless vs. Lossy). Cannot use omni antenna for X-Band system. |
| Coding Scheme on X-Band | R/S: **Yes** vs. NO | Advantages: Recommend by CCSDS. Reduces burst errors.<br>Disadvantages: Adds 15% overhead to data. |
| Tracking Option | **GPS** vs. Coherent Transponder<br>Note: both systems on spacecraft | Advantages: GPS provides timing data to required resolution. If it fails, a transponder backup would not provide information to required accuracy.<br>Disadvantage: Transponder would be a totally separate backup for GPS. Transponder is existing hardware on spacecraft. |
| X-Band Antenna Coverage | **Gimbaled Antenna** vs. Turn and Dump | Advantages: Allows higher data rate transmission to ground over the required field of view. Simple communications system (no splitter, no switches). Allows science observation to continue during downlink.<br>Disadvantages: Solar arrays could physically block downlink signal depending on what target the instrument is observing. Other options are available. (See System trades for future iterations). |

**Trades to be considered for future iterations:**

| Trade | Options (selection in bold) | Advantages/Disadvantages |
|---|---|---|
| Alert Signal Options | Commercial Network vs. **TDRSS** | Advantages: Several commercial networks (Iridium, Globalstar) are becoming available.<br>Disadvantages: TDRSS requires TDRSS transponder. Increases cost. |
| X-Band Antenna Options | **One Gimbaled Antenna** vs. One gimbaled and one body mounted | Advantages: The body-mounted antenna may add enough coverage to compensate for the solar array blockage of the gimbaled antenna.<br>Disadvantages: More complicated communications subsystem. |

### 4.5.1.5 Communications Analyses & Study Results




Communications Block Diagram

## COMMUNICATION LINK PERFORMANCE SUMMARY

### S-Band Downlink (Housekeeping Data to Ground Station)

| Parameter | Value |
|---|---|
| RF Output Power | 5 watts |
| Frequency | 2287.5 MHz |
| Spacecraft Antenna | Omnis |
| Data Rate | 400 kbps |
| Bit Error Rate | 10E-5 |
| Ground Station Antenna Size | 5 meter |
| Coding | None |
| Performance Margin | 3 dB |
| Margin (final) | 6 dB |

For a detailed analysis, see the study below.

TABLE A-1 DOWNLINK
FREQUENCY - 2287.500 MHZ
GROUND ANTENNA- ~ - 5-METER
POWER - 5.00 WATTS
NO CODING PCM/PM MI = 1RAD

| PARAMETERS | UNITS | VALUES (MAX RNG: 2329.03 KM 5.0 EL) | (MIN RNG: 600.00 KM 90.0 EL) | ESTIMATED TOLERANCES DB FAV | ADV |
|---|---|---|---|---|---|
| TOTAL TRANSMITTER POWER - | DBM | 37.0 | 37.0 | 1.0 | -1.0 |
| SPACECRAFT PASSIVE LOSSES | DB | -3.0 | -3.0 | .3 | -.3 |
| SPACECRAFT ANTENNA GAIN | DBI | -3.0 | -3.0 | .0 | .0 |
| FREE SPACE DISPERSION LOSS | DB | -167.0 | -155.2 | .0 | .0 |
| ATMOSPHERIC LOSS | DB | -.5 | .0 | .0 | .0 |
| STDN ANTENNA GAIN (EFFECTIVE) | DBI | 38.5 | 38.5 | .0 | .0 |
| COMBINER LOSS | DB | -.5 | -.5 | .0 | .0 |
| POLARIZATION LOSS | DB | -.0 | -.0 | .0 | .0 |
| MAXIMUM TOTAL RECEIVED POWER | DBM | -98.5 | -86.2 | 1.0 | -1.0 |
| SPACECRAFT ANTENNA NULL DEPTH | DB | .0 | .0 | .0 | .0 |
| MINIMUM TOTAL RECEIVED POWER | DBM | -98.5 | -86.2 | 1.0 | -1.0 |
| SYSTEM NOISE DENSITY | DBM/HZ | -175.6 | -177.0 | .0 | .0 |
| IF NOISE BW( 1000.000 KHZ) | DB-HZ | 60.0 | 60.0 | .0 | .0 |
| IF SNR (MIN) | DB | 17.1 | 30.8 | 1.0 | -1.0 |
| **CARRIER CHANNEL** | | | | | |
| CARRIER/TOTAL POWER | DB | -5.3 | -5.3 | .5 | -.5 |
| RECEIVED CARRIER POWER (MIN) | DBM | -103.8 | -91.5 | 1.2 | -1.2 |
| CARRIER LOOP NOISE BANDWIDTH(300000. HZ) | DB-HZ | 54.8 | 54.8 | .0 | .0 |
| NOISE POWER | DBM | -120.8 | -122.2 | .0 | .0 |
| CARRIER/NOISE | DB | 17.0 | 30.7 | 1.2 | -1.2 |
| REQUIRED CARRIER/NOISE | DB | -15.0 | -15.0 | .0 | .0 |
| AVAILABLE CARRIER MARGIN | DB | 32.0 | 45.7 | 1.2 | -1.2 |
| REQUIRED PERFORMANCE MARGIN | DB | 3.0 | 3.0 | .0 | .0 |
| NET MARGIN | DB | 29.0 | 42.7 | 1.2 | -1.2 |
| **DATA CHANNEL (PCM/PM)** | | | | | |
| DATA/TOTAL POWER(MI=1.00 RAD) | DB | -1.5 | -1.5 | .2 | -.2 |
| RECEIVED DATA POWER (MIN) | DBM | -100.0 | -87.7 | 1.1 | -1.1 |
| INFORMATION RATE( 400.000 KBPS) | DB-BPS | 56.0 | 56.0 | .0 | .0 |
| AVAILABLE SIGNAL/NOISE DENSITY | DB-HZ | 75.6 | 89.3 | 1.1 | -1.1 |
| REQUIRED ENERGY PER BIT/NOISE DENSITY (BER= E-5 ) | DB | 10.6 | 10.6 | .0 | .0 |
| REQUIRED SIGNAL/NOISE DENSITY | DB-HZ | 66.6 | 66.6 | .0 | .0 |
| AVAILABLE SIGNAL MARGIN | DB | 9.0 | 22.7 | 1.1 | -1.1 |
| REQUIRED PERFORMANCE MARGIN | DB | 3.0 | 3.0 | .0 | .0 |
| NET MARGIN | DB | 6.0 | 19.7 | 1.1 | -1.1 |

GLAST S-Band Downlink

**S-Band Uplink (Commands from Ground Station)**

| Parameter | Value |
|---|---|
| Ground Station RF Output Power | 200 watts |
| Frequency | 2106.4 MHz |
| Ground Station Antenna Size | 5 meter |
| Command Rate | 2 kbps |
| Bit Error Rate | 10E-5 |
| Spacecraft Antenna | Omnis |
| Command Mode | PSK/PCM/PM |
| Performance Margin | 3 dB |
| Margin (final) | 32.5 dB |

For a detailed analysis, see the table below.

TABLE A-1 UPLINK
FREQUENCY - 2106.400 MHZ
GROUND ANTENNA - - - 5-METER
POWER - .2000 K WATTS
COMMAND MODE PCM/PSK/PM S.C. FREQ= 16KHZ
DATA RATE = 2 KBPS

| PARAMETERS | UNITS | VALUES (MAX RNG: 2329.03KM 5.0 EL) | (MIN RNG: 600.00 KM 90.0 EL) | ESTIMATED TOLERANCES FAV | ADV |
|---|---|---|---|---|---|
| EFFECTIVE RADIATED POWER | DBM | 89.2 | 89.2 | 1.0 | -1.0 |
| FREE SPACE DISPERSION LOSS | DB | -166.3 | 154.5 | .0 | .0 |
| ATMOSPHERIC LOSS | DB | -.4 | .0 | .0 | .0 |
| POLARIZATION LOSS | DB | -3.0 | -3.0 | .0 | .0 |
| SPACECRAFT ANTENNA GAIN | DBI | .0 | .0 | .0 | .0 |
| SPACECRAFT PASSIVE LOSS | DB | -3.0 | -3.0 | .3 | -.3 |
| MAXIMUM TOTAL RECEIVED POWER | DBM | -83.5 | -71.3 | 1.0 | -1.0 |
| SPACECRAFT ANTENNA NULL DEPTH | DB | .0 | .0 | .0 | .0 |
| MINIMUM TOTAL RECEIVED POWER | DBM | -83.5 | -71.3 | 1.0 | -1.0 |
| SYSTEM NOISE DENSITY | DBM/HZ | -168.6 | -168.6 | .0 | .0 |
| IF NOISE BANDWIDTH 3000.000 KHZ) | DB-HZ | 64.8 | 64.8 | .0 | .0 |
| IF NOISE POWER | DBM | -103.8 | -103.8 | .0 | .0 |
| IF SNR (MIN) | DB | 20.3 | 32.5 | 1.0 | -1.0 |
| **CARRIER CHANNEL** | | | | | |
| CARRIER/TOTAL POWER | DB | -2.3 | -2.3 | .2 | -.2 |
| RECEIVED CARRIER POWER | DBM | -85.8 | -73.6 | 1.1 | -1.1 |
| CARRIER LOOP NOISE BW( 800. HZ) | DB-HZ | 29.0 | 29.0 | .0 | .0 |
| NOISE POWER | DBM | -139.6 | -139.6 | .0 | .0 |
| CARRIER/NOISE | DB | 53.8 | 66.0 | 1.1 | -1.1 |
| REQUIRED CARRIER/NOISE | DB | 20.0 | 20.0 | .0 | .0 |
| AVAILABLE CARRIER MARGIN | DB | 33.8 | 46.0 | 1.1 | -1.1 |
| REQUIRED PERFORMANCE MARGIN | DB | 3.0 | 3.0 | .0 | .0 |
| NET MARGIN | DB | 30.8 | 43.0 | 1.1 | -1.1 |
| **COMMAND CHANNEL (PCM/PSK/PM)** | | | | | |
| COMMAND/TOTAL POWER(MI=1.00 RAD) | DB | -4.1 | -4.1 | .4 | -.4 |
| RECEIVED COMMAND POWER | DBM | -87.6 | -75.4 | 1.1 | -1.1 |
| PREDETECTION (PSK) NOISE BW(32.000 KHZ) | DB-HZ | 45.1 | 45.1 | .0 | .0 |
| PREDETECTION (PSK) NOISE POWER | DB | -123.5 | -123.5 | .0 | .0 |
| PREDETECTION (PSK) SNR | DB | 35.9 | 48.1 | 1.1 | -1.1 |
| COMMAND DATA RATE ( 2.000KBPS) | DB-BPS | | | | |
| AVAILABLE ENERGY PER BIT/NOISE DENSITY | DB | 48.0 | 60.2 | 1.1 | -1.1 |
| DECODER DEGRADATION | DB | -2.0 | -2.0 | .0 | .0 |
| REQUIRED ENERGY PER BIT/NOISE DENSITY (BER=E-5) | DB | 10.5 | 10.5 | .0 | .0 |
| AVAILABLE COMMAND MARGIN | DB | 35.5 | 47.7 | 1.1 | -1.1 |
| REQUIRED PERFORMANCE MARGIN | DB | 3.0 | 3.0 | .0 | .0 |
| NET MARGIN | DB | 32.5 | 44.7 | 1.1 | -1.1 |

GLAST Communications Uplink

**S-Band Return Link (Alert Signal via TDRSS)**

| Parameter | Value |
|---|---|
| RF Output Power | 5 watts |
| Frequency | 2287.5 MHz |
| Spacecraft Antenna | Omnis |
| Data Rate | 1 kbps |
| Bit Error Rate | 10E-5 |
| Relay System | TDRSS-East to WSGTU |
| Service | Multiple Access (MA) |
| Data Group/Mode | DG1 Mode 1 |
| Coding | Rate ½ Convolutional Code |
| Performance Margin | 3 dB |
| Margin (final) | -0.27 dB |
| TDRSS Compatible | Yes |

For a detailed analysis see the table below.

```
*** RETURN LINK CALCULATION -- NETWORK SYSTEMS ENGINEER ANALYSIS **.
GSFC C.L.A.S.S. ANALYSIS #0 DATE & TIME: 9/23/97 10:11:49 PERFORMED BY: R VENTO
USERID: GLAST                    LINKID: MA                    RELAY SYS: TDRSS-East to WSGTU
 SERVICE:     FREQUENCY:    DATA GROUP/MODE:  POLARIZATION:  RANGE CASE      NOMINAL RANGE
    MA        2287.5 MHz         DG-1 MODE-1                 LCP             MAXIMUM
------------------------------------------------------------------------------------------
                              I CHANNEL                         Q CHANNEL
                           DATA RATE = 1.00 KBPS            DATA RATE = 1.00 KBPS
                           MOD 2 ADDED TO PN                MOD 2 ADDED TO PN
                           SYMBL FMT = NRZ-L                SYMBL FMT = NRZ-L
                           RATE 1/2 CODED          RATE 1/2 CODED
                           COMBINED                         COMBINED
SPACE-SPACE LINK                       NOTES
-----------------------------------------     ----------------------------------
1 USER TRANSMIT POWER, dBW                 7.00                User Provided Data
2 PASSIVE LOSS, dB                         3.00                User Provided Data
3 USER ANTENNA GAIN, dBi                   -3.00               User Provided Data
4 POINTING LOSS, dB                        .00                 User Provided Data
5 USER EIRP, dBW                           1.00                (1)-(2)+(3)-(4)
6 SPACE LOSS, dB                           192.57              CLASS Analysis
7 ATMOSPHERIC LOSS, dB                     .00                 Not Considered
8 MULTIPATH LOSS, dB                       .00                 Not Considered
9 POLARIZATION LOSS, dB                    .00                 User Provided Data
10 Prec AT INPUT TO TDRS,, dBW             -191.57             (5)-(6)-(7)-(8)-(9)
11 TDRS SINGLE ELEMENT G/T, dB/K           -11.17              CLASS Database
12 SELF/MUTUAL INTERFERENCE LOSS, dB       2.00                CLASS Database
13 C/NO AT TDRS, dB-Hz                     23.86               (10)+(11)-(12)-K
14 BANDWIDTH, dB-HZ                  .     68.54               CLASS Database
15 C/N AT TDRS, dB                         -44.68              (13)-(14)
-----------------------------------------     ----------------------------------
SPACE-GROUND LINK
-----------------------------------------     ----------------------------------
16 TDRS EIRP, dBW                          26.33               CLASS Database
17 PATH LOSS, dB                           207.32              CLASS Analysis
18 ATMOSPHERIC LOSS, dB                    .25                 CLASS Analysis
19 POLARIZATION LOSS, dB                   .03                 CLASS Database
20 RAIN ATTENUATION, dB                    6.00                User Provided Reference Value
21 Prec AT GROUND, dBW                     -187.27             (16)-(17)-(18)-(19)-(20)
22 GROUND G/T, dB/K                        41.00               CLASS Database
23 TDRS Dwnlnk C/NO (Thermal), dB-Hz       82.33               (21)+(22)-K
24 IM/XPOL DEGRADATION, dB                 3.94                CLASS Analysis (P/IM = 28.34 dB)
25 TDRS Downlink C/NO (TOTAL), dB-Hz       78.39               (23)-(24)
26 BANDWIDTH, dB-HZ                        68.54               CLASS Database
27 TDRS Downlink C/N (TOTAL), dB           9.86                (25)-(26)
-----------------------------------------     --------------------------------   --
GROUND  TERMINAL
-----------------------------------------     ----------------------------------
 28 C/N AT GROUND, dB            -45.11                        (15) || (27)
 29 BANDWIDTH, dB-HZ              68.54                        CLASS Database
 30 MA NET COMBINER GAIN, dB          13.67                    CLASS Database, inc. beamf. loss
 31 C/NO AT GROUND, dB-Hz          37.10                       (28)+(29)+(30)
                                                I-Ch     Q-Ch
                                                ----     ----
 32 CHANNEL POWER SPLIT, dB                     -3.01    -3.01   User Provided Data
 33 CHANNEL C/NO AT GROUND, dB-Hz               34.09    34.09   (29)+(30)
 34 BIT RATE, dB-BPS                            30.00    30.00   User Provided Data
 35 EB/N0 INTO DEMODULATOR, dB                  4.09     4.09    (31)-(32)
 36 DYNAMICS LOSS, dB                           .00      .00     Not Considered
 37 USER CONSTRAINT LOSS, dB                    .00      .16     CLASS Analysis
 38 RFI LOSS, dB                                .50      .50     CLASS Analysis
 39 IMPLEMENTATION LOSS, dB                     2.50     2.50    CLASS Analysis
 40 NET EB/N0, dB                               0.93     0.93    (33)-(34)-(35)-(36)-(37)
 41 THEORETICAL REQ EB/N0, dB                   4.20     4.20    BER=1E-5
 42 MARGIN, dB                                  -11.34           (40)-(41)
 43 COMBINED MARGIN, dB                         -0.27            CLASS ANALYSIS
------------------------------------------------------------------------------------------
RETURN LINK COMPATIBILITY CHECK:
!!! The link is FULLY COMPATIBLE !!!
---------------------------------------------------------------------------
```

GLAST TDRSS Return Link

**S-Band Forward Link (Software Update via TDRSS)**

| Parameter | Value |
|---|---|
| Relay Satellite | TDRSS-East |
| Service | S-Band Single Access (SSA) |
| TDRSS EIRP | 46.1dBW |
| Frequency | 2106.4 MHz |
| Spacecraft Antenna | Omnis |
| Command Rate | 4 kbps |
| Bit Error Rate | 10E-5 |
| Ground Station Size | 5 meter |
| Performance Margin | 3 dB |
| Margin (final) | 0.4 dB |
| TDRSS Compatible | Yes |

For a detailed analysis see the table below.

*** FORWARD LINK MARGIN CALCULATION – NETWORK SYSTEM ANAYSIS ***
GSFC C.L.A.S.S. ANALYSIS #1 DATE & TIME 9/23/97 10:19:3 PERFORMED BY R VENTO
USERID: GLAST LINKID: SSA RELAY SAT: TDRS-East
SERVICE: FREQUENCY DATA RATE: POLARIZATION: RANGE CASE: NOMINAL RANGE: RUN TYPE
SSA 2106.4 MHz 8.000 KBPS RCP MAXIMUM ICD

--COHERENT LINK

| PARAMETER REMARKS | | VALUE | TOLERANCE | |
|---|---|---|---|---|
| 1. RELAY NETWORK EIRP– DBW | | 46.1 | - | STDN 101.2 |
| 2. FREE SPACE LOSS – DB | | 191.9 | - | NOTE B; |
| 3. POLARIZATION LOSS – DB | | .0 | .0 | NOTE A |
| 4. USER ANTENNA GAIN – DB | | -3.0 | .2 | NOTE A |
| 5. USER ANTENNA POINTING LOSS – DB | | .0 | .0 | NOTE A |
| 6. USER PASSIVE LOSS – DB | 3.0 | .1 | NOTE A | |
| 7. USER RECEIVED POWER – DB | | -151.8 | - | SUM 1 THR |
| 8. USER COMPATIBILITY LOSS – DB | .0 | .0 | | NOTE B |
| 9. ATMOSPHERIC LOSS – DB | | * | * | NOTE B |
| 10. RFI LOSS – DB | | * | * | NOTE B |
| 11. DYNAMICS LOSS – DB | | * | * | NOTE B |
| 12. USER EFECTIVE RECEIVEFD POWER – DBW | | -151.8 | - | SUM 7 THR |
| 13. USER NOISE SENSITIVITY – DBW/HZ | | -201.6 | .3 | NOTE A |
| 14. USER RECEIVED-P/NO-DB-HZ | | 49.8 | - | 12 MINUS |
| 15. USER REQUIRED ACQUISITION –P/NO-DB-HZ | 39.5 | 3.0 | | NOTE A |
| 16. USER ACQUISITION MARGIN –DB | | 10.3 | - | 14 MINUS |
| | | | -3.6 SUM (NOTE C) | |
| | | | -3.0 RSS | |
| 17. COMMAND TO TOTAL POWER RATIO – DB | | -.5 | - | NOTE A |
| 18. USER TRANSPONDER LOSS – DB | | 2.4 | 1.0 | NOTE A |
| 19. RECEIVED COMMAND-P/NO-DB | | 46.9 | - | SUM 14,17, |
| 20. COMMAND DATA RATE – DB-HZ | | 39.0 | - | NOTE A |
| 21. USER RECEIVED EB/NO - DB | | 7.9 | 1.0 | 19 MINUS |
| 22. USER REQUIRED EB/NO – DB | | 10.5 | - | NOTE A |
| 23. EFFECTIVE USER COMMAND MARGIN – DB | | -2.6 | - | 21 MINUS |
| | | | -2.6 SUM (NOTE C) | |
| | | | -1.5 RSS | |

NOTE A PARAMETER VALUE FROM USER PROJECT - SUBJECT TO CHANGE

GLAST TDRSS Forward Link

**X-Band Downlink (Science Data to Ground Station)**

| Parameter | Value |
|---|---|
| RF Output Power | 5 watts |
| Frequency | 8200 MHz |
| Spacecraft Antenna Gain | 10 dB |
| Data Rate | 68Mbps |
| Bit Error Rate | 10E-6 |
| Ground Station Size | 5 meter |
| Coding | Rate ½ convolutional & Reed-Solomon |
| Performance Margin | 3 dB |
| Margin (final) | 8.61 dB |

For a detailed analysis see the table below.

*** DOWNLINK MARGIN CALCULATION ***
GSFC C.L.A.S.S. ANALYSIS #2 DATE & TIME 9/22/97 13:45:49 PERFORMED BY R VENTO
LINKID: 1
FREQUENCY 8200.0 MHz RANGE: 2329.0 POLARIZATION: RHCP
MODULATION: BPSK
DATA RATE: 68000.000 kbps
CODING: UNCODED
BER: 1.00E-06

| PARAMETER | VALUE | REMARKS |
|---|---|---|
| 01. USER TRANSMITTER POWER – dBW | 6.99 | NOTE A; 5.0 Watts |
| 02. USER PASSIVE LOSS – dB | 1.00 | NOTE A; |
| 03. USER ANTENNA GAIN – dBi | 10.00 | NOTE A |
| 04. USER POINTING LOSS – dB | .00 | NOTE A |
| 05. USER EIRP – dBWi | 15.99 | 1 – 2 + 3 - 4 |
| 06. POLARIZATION LOSS – dB | .00 | NOTE A |
| 07. FREE SPACE LOSS – dB | 178.6 | NOTE B; ALT:600.0 K |
| 08. ATMOSPHERIC LOSS – dB | .51 | NOTE B |
| 09. RAIN ATTENUATION – dB | .69 | NOTE B; EXC: .10%, R<br>RHGHT: 3.8 km |
| 10. MULTIPATH LOSS – dB | .00 | NOTE A |
| 11. GROUND STATION ANTENNA GAIN – dBi | 50.07 | NOTE B; 5.0 M EFF: 55 |
| 12. GROUND STATION POINTING LOSS – dB | .00 | NOTE A |
| 13. SYSTEM NOISE TEMPERATURE - dB-DEGREES-K | 21.76 | NOTE A |
| 14. GROUND STATION G/T - dB/DEGREES-K | 28.30 | 11 –12 - 13 |
| 15. BOLTZMANN'S CONSTANT - dBW/(Hz*K) | -228.60 | CONSTANT |
| 16. RECEIVED CARRIER TO NOISE DENSITY - dB/Hz | 93.63 | 5 – 6 – 7 – 8 – 9 – 10 + 1 |
| 17. DATA RATE - dB-bps | 78.33 | NOTE A |
| 18. DIFFERENTIAL ENCODING/DECODING LOSS – dB | .00 | NOTE A |
| 19. RECEIVED Eb/No – dB | 15.31 | 16 – 17 - 18 |
| 20. IMPLEMENTATION LOSS – dB | 1.00 | NOTE A |
| 21. REQUIRED Eb/No – dB | 10.60 | NOTE A |
| 22. REQUIRED PERFORMANCE MARGIN – dB | 3.00 | NOTE A |
| 23. MARGIN – dB | .71 | 19 – 20 – 21 - 22 |

NOTE A PARAMETER VALUE FROM USER PROJECT - SUBJECT TO CHANGE
NOTE B: FROM CLASS ANALYSIS IF COMPUTED

GLAST X-Band Link

#### 4.5.1.6 Communications Components Summary

| Element | Make / Model | Qty | Mass per unit (kg) | Avg Power per unit (w) | Peak Power per unit (w) | Nom-inal Mass (kg) | Peak Power (w) | Avg. Power (w) | Dimensions (mm) | Cost ($) | Contingency (%) | Total Mass w/ Contingency | Total Peak Power w/ Contingency | Total Avg Power w/ Contigency | Comments |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| X-Band Transmitter | LMC, tbs | 2 | 3 | 0.3125 | 50 | 6 | 100 | 0.625 | 200 x 165 x 71 | 300000 | 1 | 6.06 | 101 | 0.63125 | |
| TDRSS 4th Generation Transponder | GSFC, 4th Gen | 2 | 3.6 | 6.2125 | 40 | 7.2 | 80 | 12.425 | 200 x 210 x 130 | 500000 | 1 | 7.272 | 80.8 | 12.54925 | Power information from max. in spec. |
| S-Band Band Reject Filter | Motorola, tbs | 2 | tbs | 0 | 0 | tbs | 0 | 0 | tbs | 0 | 1 | tbs | 0 | 0 | included with Transponder procurement |
| S-Band Diplexer | Motorola, tbs | 1 | tbs | 0 | 0 | tbs | 0 | 0 | tbs | 0 | 1 | tbs | 0 | 0 | included with Transponder procurement |
| S-Band Omni Antenna | J&T, 00-000056 | 2 | 0.23 | 0 | 0 | 0.46 | 0 | 0 | 114dia x 127h | 70000 | 1 | 0.4646 | 0 | 0 | |
| X-Band Antenna | ? | 1 | 0.5 | 0 | 0 | 0.5 | 0 | 0 | 50 x 50 x 25 | 500000 | 5 | 0.525 | 0 | 0 | need to find vendor |
| Hybrid | tbs | 1 | 0.5 | 0 | 0 | 0.5 | 0 | 0 | 101 x 76 x 13 | 15000 | 1 | 0.505 | 0 | 0 | |
| RF Switch | tbs | 2 | (~0.5) | 0 | 0 | (~0.5) | 0 | 0 | ~101 x 76 x 13 (guess) | tbs | 1 | | | | need to find vendor |
| Cables | tbd | 14 | 0.5 | 0 | 0 | 7 | 0 | 0 | tdb | 42000 | 1 | 7.07 | 0 | 0 | $3000 per cable (average for worst case) |
| Comm Totals | | 27 | 8.33 | 6.525 | 90 | 21.66 | 180 | 13.05 | 0 | 1427000 | 13 | 21.8966 | 181.8 | 13.1805 | |

#### 4.5.1.7 Communications New Technologies Assessment

**Fourth Generation TDRSS Transponder**

| | |
|---|---|
| Advantages: | Have S-Band transmitter and receiver capabilities in either TDRSS or STDN mode<br>Can receive 16 kbps via TDRSS for flight software update |
| Status: | currently under development, test, and flight qualification |
| Risk Assessment: | none at present |

#### 4.5.1.8 Communications Risk Assessment

**Programmatic Risks**

There are no programmatic risks. All components (with one exception) are readily available from several vendors and have been flown on many missions. The exception is the fourth generation TDRSS transponder, which is currently in the development phase.

**Technical Risks**

- S-Band Antenna Nulls

The antennas for both the S-band uplink and the downlink each produce hemispherical coverage and are mounted on opposite sides of the spacecraft resulting in a gap in coverage where the two hemispheres meet. This would only be a problem if and when the spacecraft orientation places the ground station within the null. There are several solutions available: modifying the communications subsystem design to allow for more antennas and using redundant ground stations. The command uplink has some margin, which may be sufficient to allow the ground station commands to be received even if the station is in the null. The data downlink does not have sufficient margin for this. Therefore, the risk to the mission is considered to be minimal.

## 4.6 Thermal

### 4.6.1.0 Thermal Design – Iteration 1

### 4.6.1.1 Thermal Overview

The thermal control subsystem (TCS) herein described pertains to both the GLAST instrument TCS and the spacecraft bus TCS. The level of description and design detail is appropriate for a top-level mission design study or concept definition.

**GLAST Instrument Thermal Control**

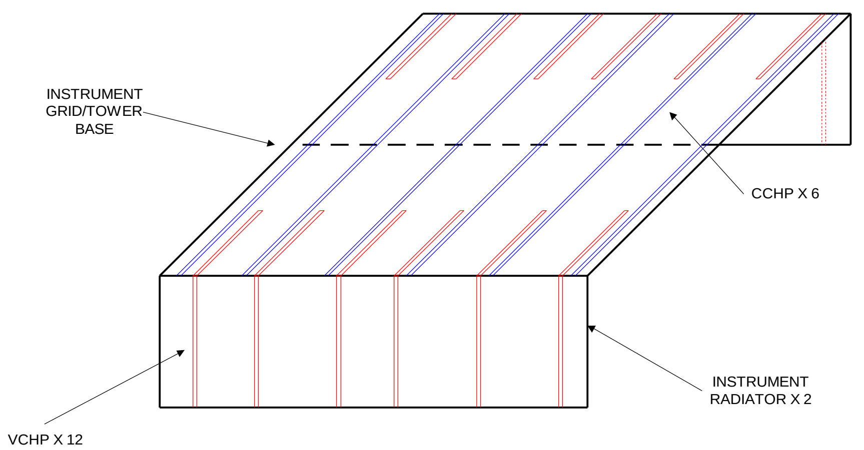
The thermal subsystem design of the GLAST instrument is assumed to be the responsibility of the instrument provider. Due to the configuration and size of the instrument it is evident that the spacecraft bus must consider the thermal control requirements of the instrument.

The dominant driver of the instrument thermal control design is the need to dissipate up to 650 watts of instrument power. The twenty-five detector towers conduct their heat downward to the tower interface grid. This grid then is required to spread and transport the heat to external radiators where it can be radiated to space. Constant conductance heat pipes (CCHP) are imbedded within the grid to efficiently transport heat throughout the grid with very little temperature gradient. The instrument design presented within this study then assumes that a system of variable conductance heat pipes (VCHPs) transport the heat from the grid to the external radiators.

**VCHP Description**

The choice to baseline VCHPs was based on the desire to maximize instrument temperature stability under a variety of orbit and attitude induced thermal environments. VCHPs also are very affective at minimizing the amount of needed operational and safehold/launch heater power. A VCHP operates by basically shutting down radiator area as needed by self regulating its efficiency. The layout chosen keeps all of the VCHPs in a single spacecraft Y-Z plane thus providing an easy configuration to test on the ground. The two instrument radiators are located in the X-Z plane in order to minimize solar exposure.

Given the desired reliability of GLAST mission, it is recommended that any heat pipe system chosen for the instrument heat rejection system be carefully analyzed to insure appropriate heat pipe redundancy. Although heat pipes are quite flight proven and highly reliable, analyses should insure that if a reasonable number of pipes fail, mission success is not jeopardized.




**Instrument VCHP/CCHP Layout Concept**

Instrument VCHP/CCHP Layout Concept

**Spacecraft Thermal Control**

Given the routine thermal requirements typical of the components needed for the spacecraft bus, the spacecraft bus will employ basic thermal engineering design practice. However, due to the variety of attitudes desired, it will probably be necessary to employ both active thermal control (via the use of VCHPs, etc.) in addition to passive thermal control.

Spacecraft components will be typically mounted to one of the spacecraft's five available panels. In addition to providing structural support, these panels will also double as radiators. Multi-layer insulation (MLI) will be used to size the radiators as needed. Heaters and thermostats will be employed to keep components warm during extreme attitudes or low power operational configurations. Once again, due to the needed reliability of the GLAST mission, it is expected that all thermal control components be fully redundant.

### 4.6.1.2 Thermal Assumptions

| | |
|---|---|
| GLAST Instrument Radiator Temperature Requirements : | 0 to 10 °C (top of towers at 15 to 25 °C) |
| GLAST Instrument Thermal Stability: | <= 1 °C/orbit |
| GLAST Instrument Radiator Requirements: | 650 watts at 0 °C |
| Spacecraft Components Temperature Requirements: | 0 to 40 °C |
| Spacecraft/Instrument Grid Isolation: | Thermal isolation should be considered in the interface mechanical design. |
| Spacecraft Attitude: | Sun can be anywhere in X-Z plane. Instrument is generally zenith pointing. |
| Spacecraft Radiator Requirements: | >= 450 watts at 40 °C |

### 4.6.1.3 Thermal Derived Requirements

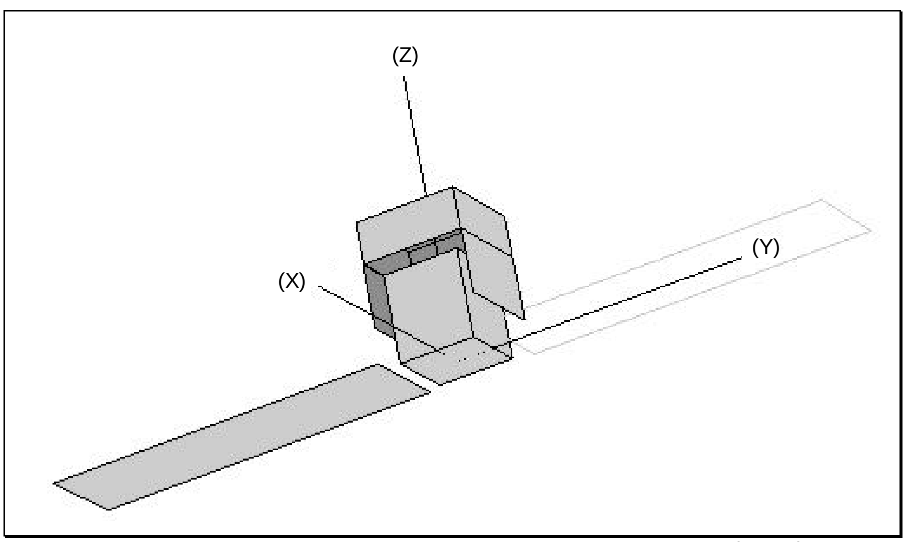
None identified. As development continues, pointing restrictions needed to enhance thermal performance may be identified.

### 4.6.1.4 Thermal Trades Matrix

No trades identified for iteration 1.

### 4.6.1.5 Thermal Analyses & Study Results

A geometric model of the spacecraft was created to assess the spacecraft's thermal environment and determine required radiator sizes.




GLAST Thermal Geometry Model

### Instrument Radiator Size Requirement

A total of 2.4m$^2$ or instrument radiator is needed to dissipate 600 watts at 0°C. The two X-Z plane radiators for this design were sized at ~3.5m$^2$ total in order to allow for heat backloading from the solar arrays, earth IR and UV albedo energy. Using the geometric model created and analyzing a zenith oriented attitude at a high solar beta angle of 52°, it was determined that the radiators as currently configured could effectively dissipate 650 watts of instrument power at 5°C. Silvered Teflon was assumed to be the radiator coating with an $\alpha/\varepsilon$ =0.12/0.8.

### Spacecraft Radiator Capability

Again, assuming silvered Teflon and the orbit mentioned in 3.2.1.2 and 4.6.1, each of the spacecraft's five exposed sides were analyzed for their total heat radiating capacity at 30°C. Environmental heating and solar array back loading were accounted for.

| Panel | Capability |
|---|---|
| +Y Panel | 209 watts |
| -X Panel | 488 watts |
| -Y Panel | 212 watts |
| +X Panel | 499 watts |
| -Z Panel | 307 watts |

These capabilities do not account for the numerous cut outs and blockages that will result from a more detailed spacecraft design. However, it is apparent that the current configuration is quite capable of dissipating the expected ~450 watts of spacecraft power.

### 4.6.1.6 Thermal Components Summary

| **Component Summary** | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Element** | **Make/Model** | **Quantity** | **Mass per unit (kg)** | **Avg Power per unit (w)** | **Peak Power per unit (w)** | **Nominal Mass (kg)** | **Peak Power (w)** | **Avg. Power (w)** | **Dimensions (mm)** | **Cost ($)** | **Contingency (%)** | **Total Mass w/ Contingeny** | **Total Peak Power w/ Contigency** | **Total Avg.Power w/ Contigency** |
| Thermostats | | 60 | 0.0085 | | | 0.51 | 0 | 0 | | | 1 | 0.5151 | 0 | 0 |
| Heaters | | 0.3 | 0.14 | | | 0.042 | 120 | 40 | | | 1 | 0.04242 | 120 | 40.4 |
| MLI | | 17.6 | 0.503 | | | 8.8528 | 0 | 0 | | | 1 | 8.941328 | 0 | 0 |
| Paint/Coatings | | 8.8 | 0.161 | | | 1.4168 | 0 | 0 | | | 1 | 1.430968 | 0 | 0 |
| Heat Pipes | | 24 | 0.15 | | | 3.6 | 0 | 0 | | | 1 | 3.636 | 0 | 0 |
| Doublers | | | | | | | | | | | 1 | | 0 | 0 |
| | | | | | | | | | | | | | 0 | 0 |
| | | | | | | | | | | | | | 0 | 0 |
| THML Totals | | | 0 | 0 | 0 | 14.4216 | 120 | 40 | 0 | 0 | | 14.57 | 57.5 | 57.5 |

### 4.6.1.7 Thermal New Technologies Assessment

No new thermal control technologies have been incorporated into this mission study.

### 4.6.1.8 Thermal Risk Assessment

There are no high-risk elements associated with the thermal control subsystems.

## 4.7 Command & Data Handling

### 4.7.1.0 Command & Data Handling Design – Iteration 1

### 4.7.1.1 Command & Data Handling Overview

C&DH subsystem provides commanding, telemetry, engineering data storage/playback services for the GLAST spacecraft during all mission phases. It also provides on board computer (OBC) to act as host for the flight software. The OBC and the flight software provide control of all spacecraft functions including commanding (real-time and stored commanding), telemetry processing, engineering data storage/playback, redundancy management, Power subsystem management support, Thermal subsystem management support, Sensor data processing, Attitude control, and 1553B Bus control.

The C&DH design concepts and hardware have been derived from the MIDEX Advanced Distributed Architecture. It is designed with high degree of standardization, modularity, reliability and flexibility while maintaining low power, low volume, and low cost.

The C&DH subsystem block diagram is shown in Figure 1. The recommended OBC is Mongoose V, 32-bit rad-hard RISC processor that has 4 Mbytes of EEPROM and 2 Gbits of user memory for program memory/bulk storage. To protect the memory against SEUs, a single bit correct, double bit detect EDAC is provided.

The uplink/down link card performs command decoding/distribution, emergency hardware switching, and format/down-link engineering data to the S-band transponder. The telemetry encoding will include CCSDS and ½ rate convolutional encoding.

The housekeeping RSN/Instrument RSN provide a standardized interface approach that enables various spacecraft components and instrument to interface with the C&DH subsystem architecture. The RSN functions include telemetry collection, formatting, command decode/distribution, and power switching.

All science data collection and storage functions will reside in the instrument subsystem. The playback of science data is transferred to the C&DH subsystem's X-band Formatter board over the high bandwidth Fiber Optic Data bus (FODB). The X-band Formatter will receive playback data at 68Mbps and perform CCSDS, Reed-Solomon, and Convolutional encoding prior to down-linking formatted data to the X-band transmitter (see Figure 2).

#### 4.7.1.2 Command & Data Handling Assumptions

- One 9 min contact per day (Wallops).
- 28.7 deg inclination.
- 600 km, Circular Orbit
- C&DH does not store GLAST data. C&DH provides science data formatting function only.
- Downlink mission data on X-band, Spacecraft HSKP data and alert signal on S-band (GN Mode). Alert on S-Band (TDRS mode) during non contact.
- Instrument memory load, requiring more than one ground contact, can be segmented for multiple loads.
- Adopt Space Communications Protocol Standard (SCPS) protocol when available.
- No R/S Encoding required on S-band downlink.
- Additional ground pass can be scheduled to accommodate for bad pass.

### 4.7.1.3 Command & Data Handling Derived Requirements

**General Requirements**

- Provide Redundant C&DH System
- Receive Unswitched +28V from Power Subsystem
- Provide autonomous spacecraft operation for up to 168 hours
- Provide Warm Spare Processing Capability (Both Processors loaded and running, but only the Controlled Processor performs commanding and control functions. If the control processor fails, the backup takes over with some interruption to the mission.)

**Science Data**

- Receive GLAST mission and HSKP playback Data at 68Mbps over the FODB, provide formatting and transmit formatted data to X-Band Transmitter.
- Provide capability to downlink gamma ray burst alerts at 1kbps to S-Band transponder.

**Spacecraft Housekeeping Data**

- Collect S/C and instrument Housekeeping Data at 2.0 Kbps Over the 1553B Bus
- Perform CCSDS Encoding on Downlink
- Perform convolutional encoding.

**Commanding**

- Receive CCSDS Compliant Telecommands at 2 kbps Bit Rate
- Provide 3 bit Error Detection/2 bit Error Correction Capability
- Distribute Uplink Command Packets via the 1553B Bus
- Provide Stored Commanding Capability
- Provide Hardware Decoded Commanding Capability
- Provide Discrete Commanding Capability

**Timing**

- Receive 1 pulse per second signal from GPS
- Maintain Spacecraft Timecode to 1us resolution
- Accuracy: 5usec

**Onboard Spacecraft Data Storage**

- Provide Capacity to Store up to 400 Mbit of Spacecraft Data
- Provide Error Detection and Correction Capability
- Provide Capability to Disable EDAC Function
- Record Rate: 2kbps
- Playback Rate: 400Kbps
- Provide Simultaneous Record/Playback Capability
- BER Less Than 10E-9

**Power**

- 72W nominal, 135W max

**Mass**

- 30 Kg

**Size**

- TBD mm3

**Radiation**

- TBD Krad total dose, LET >TBDMeV

**Mission Life**

- 5year

### 4.7.1.4 Command & Data Handling Trades Matrix

| Trade | Options (selection in bold) | Advantages/Disadvantages |
|---|---|---|
| Processor Redundancy | **Warm Backup** vs. Hot Backup | Hot Backup Advantages: No ground intervention necessary to recover from processor failure, no loss of science with processor failure.<br><br>Hot Backup Disadvantages: high cost to accommodate synchronous operation of the flight software and flight hardware **.**<br><br>Warm Spare Backup Disadvantages: loss of some mission data, requires ground intervention to recover from processor failure.<br><br>Advantages of warm spare backup: cheaper, simpler software hardware design. |
| System Bus | **1553B bus** vs. 1773 bus | 1553B advantages: Easier and cheaper to implement, no special test equipment needed, availability of flight parts availability, more widely used.<br><br>1553B Disadvantages: slightly more weight.<br><br>1773 BUS Disadvantages: contamination, availability of flight parts |

C&DH: Table 1.

### 4.7.1.5 Command & Data Handling Analyses & Study Results

**Downlink Rate Calculation**

The downlink rates calculation for two 10 minute contacts and one 9 minute contact are shown in Table 2. Additional contacts do not offer any advantage since the longest break between contacts is 10 hours.

**Down-Link Rate**

| **DOWNLINK RATE**<br>600KM, circular orbit, 28.7 deg inclination | | | | |
|---|---|---|---|---|
| Option 1 - DOWNLINK RATE (TWO 10 MIN CONTACTS) | | | | |
| | | CCSDS OH | R/S OH | Downlink Rate |
| S/C Eng Data @2kbps | 8.6E+07 | 9.5E+07 | | 1.6E+05 |
| Science Data @300Kbps | 1.3E+10 | 1.4E+10 | 1.6E+10 | 2.7E+07 |
| **Option 2 - DOWNLINK RATE (ONE 9 MIN CONTACT)** | | | | |
| | | **CCSDS OH** | **R/S OH** | **Downlink Rate** |
| **S/C Eng Data @2kbps** | **1.7E+08** | **1.9E+08** | | **4.0E+05** |
| **Science Data @300Kbps** | **2.6E+10** | **2.9E+10** | **3.3E+10** | **6.8E+07** |
| Option 2, which requires less ground contact time (and hence cheaper on operation ) is chosen. | | | | |

Table 2: Down-Link Rate

**Spacecraft Recorder Sizing**

- From Table 2 (Option 2), the spacecraft recorder requires 200Mbit for nominal operation.
- To accommodate for one bad pass operation, the capacity will be increased to 400Mbit.
- Spacecraft C&DH provides 2Gbit of user data (program, stored commands, HSKP data) storage, of which 1.0 Gbits can be allocated for recording purpose.
- Spacecraft recorder can correct single bit error and detect double bit error.
- The recorder can accommodate single DRAM failure. But, single DRAM failure will reduce the capacity by 50%.

| Instrument Recorder Sizing (Two 10 Min Contact) | |
|---|---|
| Data (bits) | 1.3E+10 |
| R/S OH (5%) | 1.4E+10 |
| Bad pass Allowance (bits) | 2.7E+10 |
| Instrument Recorder Sizing (One 9 Min Contact) | |
| Data (bits) | 2.6E+10 |
| R/S OH (5%) | 2.7E+10 |
| Bad pass Allowance (bits) | 5.4E+10 |
| It is assumed that instrument recorder will use short R/S for EDAC. | |

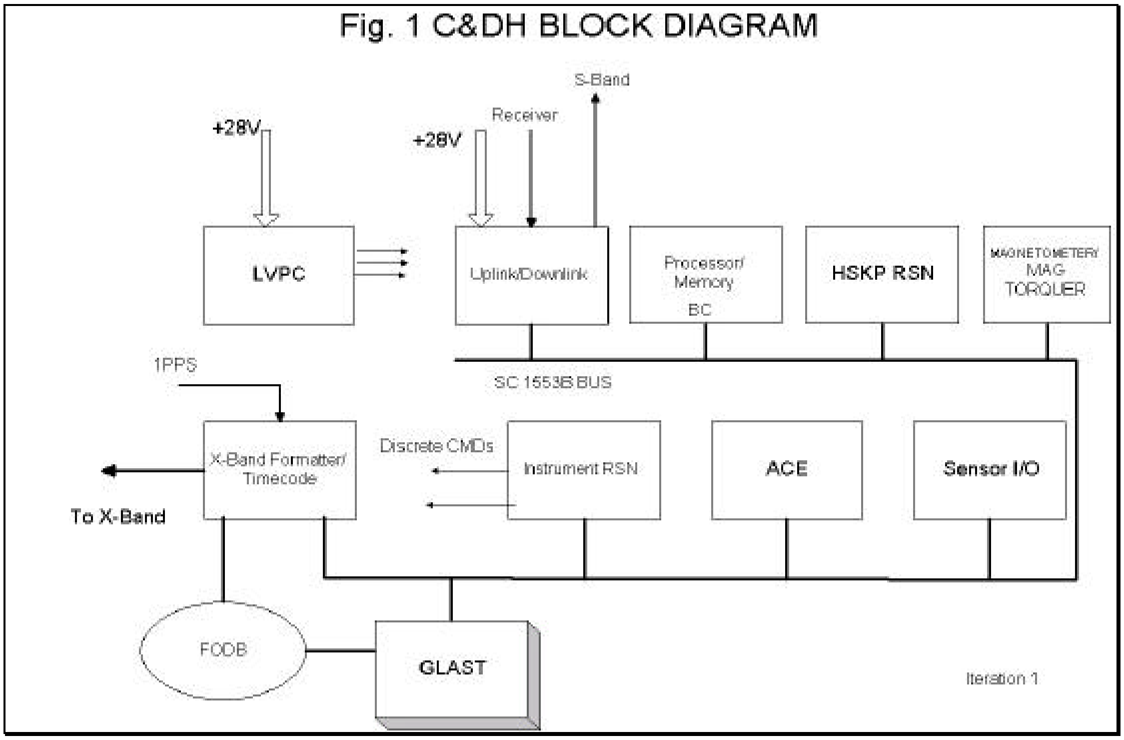
Table 3: Instrument Recorder Sizing

**Memory Bit Error Rate Calculation**

| MEMORY BIT ERROR RATE | | | | |
|---|---|---|---|---|
| **Device Upsets per day** | 26 | Landsat 7 data | Assume same upset rate | |
| **Worstcase data retention time(hours)** | 48 | | | |
| **Errors in a DRAM for worst case retention** | 52 | | | |
| **Bits in a DRAM** | 16777216 | 16 Mbit dram | GLAST uses 128Mbit DRAM. | |
| **Probability of an error in a bit** | 3.09944E-06 | | | |
| **Assumptions** | | | | |
| EDAC word is 39 bits long, 32 bits of data and 7 bits of parity n=39 | | | | |
| **Bits W/No Error** | **No. Of Bits W/ No Error** | **Probability Of Event W/BER Given Above** | | |
| 39 | 0 | 0.999879129 | | |
| 38 | 1 | 0.000117765 | | |
| 37 | 2 | 6.39726E-09 | | |
| 36 | 3 | 2.12571E-13 | | |
| 35 | 4 | 4.83161E-18 | | |
| 34 | 5 | 7.95834E-23 | | |
| 33 | 6 | 9.81826E-28 | | |
| 32 | 7 | 9.24796E-33 | | |
| 31 | 8 | 6.71805E-38 | | |
| **Number of bits w/error** | **Number of EDAC Words w/listed number of BER** | **Number of bit Error Resulting** | **No Correction** | **One Correction** |
| 0 | 999879.1289 | 0 | 0 | 0 |
| 1 | 117.765272 | 117.765272 | 117.765272 | 0 |
| 2 | 0.00639726 | 0.00639726 | 0.00639726 | 0.00639726 |
| 3 | 2.12571E-07 | 2.12571E-07 | 2.12571E-07 | 2.1257E-07 |
| 4 | 4.83161E-12 | 4.83161E-12 | 4.83161E-12 | 4.8316E-12 |
| 5 | 7.95834E-17 | 7.95834E-17 | 7.95834E-17 | 7.9583E-17 |
| 6 | 9.81826E-22 | 9.81826E-22 | 9.81826E-22 | 9.8183E-22 |
| 7 | 9.24796E-27 | 9.24796E-27 | 9.24796E-27 | 9.248E-27 |
| 8 | 6.71805E-32 | 6.71805E-32 | 6.71805E-32 | 6.7181E-32 |
| Total | 999996.9006 | 117.7716695 | 117.7716695 | 0.00639747 |
| **BER with no correction** | 3.01979E-06 | | | |
| **BER with one bit correction** | 1.64038E-10 | | | |

Table 4: Memory Bit Error Rate

Use of 2 bit detect 1 bit correct Hamming Code results in BER of $1.6\text{x}10^{-10}$. This is better than $1\text{x}10^{-9}$ BER requirement. (This assumes similar upset rate as Landsat.)




C&DH Block Diagram 1

#### 4.7.1.6 Command & Data Handling Components Summary

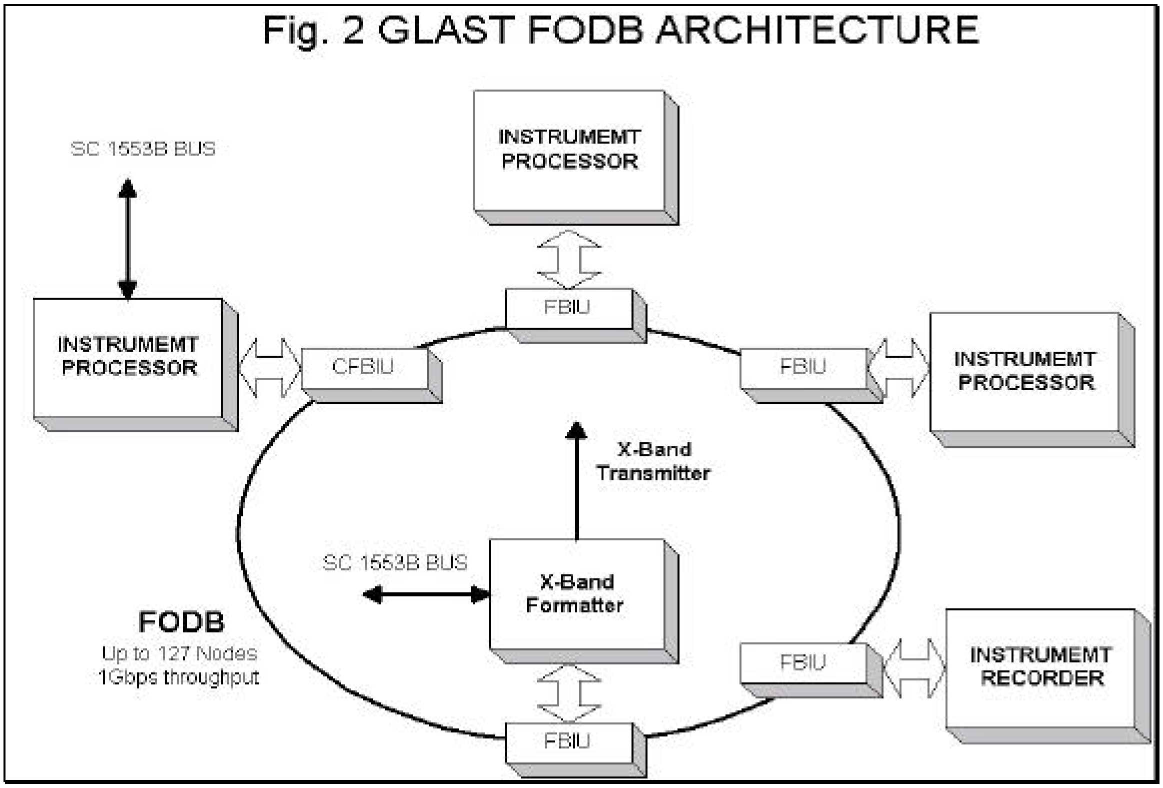



Diagram 2: C&DH FODB Architecture

The C&DH subsytem consists of 9 distinct cards plus the backplane. Power and weight of each board is summarized in the table below.

| Element | Qty | Mass per unit (kg) | Avg Power per unit (w) | Peak Power per unit (w) | Nominal Mass (kg) | Peak Power (w) | Avg. Power (w) | Dimensions (mm) | Contingency (%) | Total Mass w/ Contingeny | Total Peak Power w/ Contigency | Total Avg.Power w/ Contigency |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| C&DH (Primary) | | | | | | | | 20x12x9 in3 | | | | |
| LVPC | 1 | 1.0 | 13.0 | 0.0 | 1.0 | 0.0 | 0.0 | | 20 | 1.2 | 0.0 | 0.0 |
| Processor/memory board | 1 | 1.0 | 8.0 | 12.0 | 1.0 | 12.0 | 9.6 | | 20 | 1.2 | 14.4 | 11.5 |
| Uplink/downlink board | 1 | 1.0 | 3.3 | 4.4 | 1.0 | 4.4 | 4.0 | | 20 | 1.2 | 5.3 | 4.8 |
| Housekeeping | 1 | 1.0 | 2.5 | 3.6 | 1.0 | 3.6 | 3.0 | | 20 | 1.2 | 4.3 | 3.6 |
| Instrument RSN | 1 | 1.0 | 1.0 | 1.4 | 1.0 | 1.4 | 1.2 | | 20 | 1.2 | 1.7 | 1.4 |
| X-Band Formatter | 1 | 1.0 | 1.0 | 30.0 | 1.0 | 30.0 | 2.4 | | 20 | 1.2 | 36.0 | 2.9 |
| ACE | 1 | 1.0 | 3.9 | 5.6 | 1.0 | 5.6 | 4.7 | | 20 | 1.2 | 6.7 | 5.6 |
| Sensor I/O | 1 | 1.0 | 0.8 | 1.2 | 1.0 | 1.2 | 1.0 | | 20 | 1.2 | 1.4 | 1.2 |
| Magnetometer /Mag Torquer | 1 | 1.0 | 10.0 | 24.0 | 1.0 | 24.0 | 12.0 | | 20 | 1.2 | 28.8 | 14.4 |
| backplane | 1 | 1.0 | 1.0 | 1.2 | 1.0 | 1.2 | 1.2 | | 20 | 1.2 | 1.4 | 1.4 |
| Chassis | 1 | 1.0 | 0.0 | 0.0 | 1.0 | 0.0 | 0.0 | | 20 | 1.2 | 0.0 | 0.0 |
| | | | | | | | | | | | | |
| C&DH (Redundant) | | | | | | | | 20x12x9 in3 | | | | |
| LVPC | 1 | 1.0 | 13.0 | 0.0 | 1.0 | 0.0 | 0.0 | | 20 | 1.2 | 0.0 | 0.0 |
| Processor board | 1 | 1.0 | 8.0 | 12.0 | 1.0 | 12.0 | 9.6 | | 20 | 1.2 | 14.4 | 11.5 |
| Uplink/down-link board | 1 | 1.0 | 3.3 | 4.4 | 1.0 | 4.4 | 4.0 | | 20 | 1.2 | 5.3 | 4.8 |
| Housekeeping | 1 | 1.0 | 0.0 | 0.0 | 1.0 | 0.0 | 0.0 | | 20 | 1.2 | 0.0 | 0.0 |
| Instrument RSN | 1 | 1.0 | 0.0 | 0.0 | 1.0 | 0.0 | 0.0 | | 20 | 1.2 | 0.0 | 0.0 |
| X-Band Formatter | 1 | 1.0 | 0.0 | 0.0 | 1.0 | 0.0 | 0.0 | | 20 | 1.2 | 0.0 | 0.0 |
| ACE | 1 | 1.0 | 0.0 | 0.0 | 1.0 | 0.0 | 0.0 | | 20 | 1.2 | 0.0 | 0.0 |
| Magnetometer /Mag Torquer | 1 | 1.0 | 10.0 | 0.0 | 1.0 | 0.0 | 0.0 | | 20 | 1.2 | 0.0 | 0.0 |
| Sensor I/O | 1 | 1.0 | 0.0 | 0.0 | 1.0 | 0.0 | 0.0 | | 20 | 1.2 | 0.0 | 0.0 |
| Backplane | 1 | 1.0 | 1.0 | 1.2 | 1.0 | 1.2 | 1.2 | | 20 | 1.2 | 1.4 | 1.4 |
| Chassis | 1 | 1.0 | 0.0 | 0.0 | 1.0 | 0.0 | 0.0 | | 20 | 1.2 | 0.0 | 0.0 |
| **C&DH Total** | | **22.0** | **79.8** | **101.0** | **22.0** | **101.0** | **53.9** | | | **26.4** | **121.2** | **64.7** |
| Input Power (75% efficiency) | | | | 134.7 | | | 71.9 | | | | | |

### 4.7.1.7 Command & Data Handling New Technologies Assessment

Both 128 Mbit DRAMS for OBC program memory/bulk storage and Fiber Optic Data Bus are being developed for the EO-1 SSR (WARP) which is scheduled for delivery in June 98.

The final issues of Space Communications Protocol Standards are currently scheduled to be released in year 2000.

### 4.7.1.8 Command & Data Handling Risk Assessment

All the boards will require a minor design modification to convert from 1773 bus interface to 1553B bus interface.

The X-band formatter/Timecode board is new design.

Adequate memory is provided to allow for single DRAM failure. Multiple DRAM failure will require switchover to the redundant unit.

The subsystem is fully redundant.

# 5.0 Ground Segment

## 5.0 Design Iterations

### 5.0.1 Design – Iteration 1

## 5.0 Ground Design – Baseline

The GLAST ground design has assumed the use of several existing ground facilities, with some development between now and the year 2004, when the mission is expected to be launched. Any assumptions about development of facilities are clearly identified throughout the Ground section of this report.

### 5.1 Ground Overview

GLAST will fly in a relatively low inclination orbit, at an altitude of 600 km. In order to avoid the South Atlantic Anomaly, the lowest possible orbit inclination is desired, depending on the ability of the launch vehicle to reduce the inclination from the nominal 28.7° resulting from a Cape Canaveral launch.

GLAST is depending on an X-band downlink for dump of stored data. There are few X-band receiving sites located near the equator, so an inclination of 0° would severely limit the choice of available sites to support this downlink. Availability of X-band receiving sites to support an orbit inclination of 28.7° is much better. GLAST has a requirement to send a notification of certain events from the spacecraft to users within a very short time after detecting the event. Since continuous coverage from a limited number of ground stations is not possible, the Multiple Access (MA) capability of TDRSS will be required. GLAST also has a requirement for occasional capability to send brief commands to the spacecraft for viewing targets of opportunity, which must be received by the spacecraft within 1 minute of the time the decision was made to view the event. This also will require use of the TDRSS MA forward capability.

Data will be returned from supporting ground stations to the spacecraft Mission Operations Center (MOC), where data will be processed to Level 0 and distributed to the GLAST Science Operations Center.

The performance and cost of hardware and software required to process, archive and distribute science data are not covered in this report.

## 5.2 Ground Assumptions

These are the major assumptions used in the ground system discussion. Details of the communication links are contained in Section 4.5 (Communications).

| Ground Assumptions | |
|---|---|
| Item | Required or Assumed Value |
| Launch | June 2004 |
| Lifetime | 2 years required<br>5 years desired |
| Orbit altitude | 600 km circular |
| Orbit inclination | 28.7° or less; 0° preferred to avoid SAA |
| Data Volume: | 34 Gbits/day (see C&DH analysis) |
| Ground Station Contacts/day: | At least 1 per day |
| Time of each contact: | 9 min. (8 min. of data transmission) |
| Total contact time/day: | 9 min. |
| Return Data Delivery Time | 24 hours max from time of measurement to delivery to science function |
| BER Required | $1x10^{-6}$ |
| Forward Frequency: | S-Band (commanding from GN) |
| Redundancy: | Yes |
| Notification of Gamma Ray Event | Within seconds of the event |
| Response to Targets of Opportunity | Within 1 hour (TBR) |

Table 5.2.1 Ground Assumptions

## 5.3 Ground Derived Requirements

Using the information contained in Section 5.2, the following requirements are derived.

| Ground Derived Requirements | |
|---|---|
| Item | Derived Value |
| Return Frequency: | X-Band: science data (to achieve data volume required)<br>S-band: alert signal (TDRSS only) and housekeeping |
| Downlink Data Rate Required: | X-Band: 68 Mbps (see C&DH analysis) S-Band: 400 kbps (see C&DH analysis) |
| Forward Frequency: | S-Band (available on S-Band transponder) |
| Event Notification | Requires Demand Access capability on TDRSS MA Return |
| Uplink Data Rate: | 2 Kbps (4 kbps via TDRSS for flight software update, up to 1 Mbyte in 24 hours) |
| Coding Scheme: | Reed Solomon and Rate ½ Convolutional Code |
| Ground station dish size: | 5 m (minimum) for S-Band uplink, X-Band downlink, and S-Band housekeeping downlink |

**Table 5.3.1**: Ground Derived Requirements

## 5.4 Ground Trades Matrix

The notification of a gamma ray event must be received within seconds of the event. This requires a full-time demand access capability so the spacecraft can initiate transmission of the event notice as soon as it happens. This cannot be handled by traditional S-band ground stations, as there are not enough of them to provide continuous contact. There are other event notification networks using VHF frequencies, but they cannot necessarily assure contact within seconds of an event happening. TDRSS can support this requirement in two ways:

- Utilize a full-time MA return channel, using existing TDRSS capabilities. This support is currently stated to cost $60.00 per hour, or $525,600 per year.
- Utilize a currently developing TDRSS demand access capability. This capability is currently under development, at this point in time having just passed Critical Design Review (CDR). This capability is currently expected to be available by mid-1999, which is well before GLAST would need this capability. In order to achieve this capability full-time, GLAST would have to provide dedicated equipment at the White Sands Complex to provide a beamformer and receiver capability. This equipment is currently estimated to cost $70,000, which would provide support via a single TDRSS satellite. For full-time coverage, three sets of equipment would be required at a cost of $210,000. Compared to the cost of a full-time MA return channel, this equipment would pay for itself in 145 days of operation.

## 5.5 Ground Analyses & Study Results

At present, there are few ground stations near the equator that can support an X-band downlink. Kourou and Malindi are both equipped for X-band receive, and may still be operating in 2004. However, foreign governments own both of these sites, which complicates the support arrangements. By the year 2004, the cost of obtaining this support is not clear. At present, such support is typically arranged on a "quid pro quo" basis, and typically the support is for limited periods of time, such as launch and early orbit checkout. Probably, it will cost the GLAST mission as much to pay for support from these sites as it would for equivalent NASA sites.

There is a site at Mayaguez, Puerto Rico, currently managed by the FUSE Project at the Applied Physics Laboratory, which is currently implemented only for S-band. There has been discussion of upgrading to X-band but no definite plans exist yet.

There is a Universal Space Network (commercial provider of communications services between ground-based sites and satellites) site located in Hawaii, and they want to construct another site in southern Florida or the Caribbean before GLAST would be launched. A contact at Universal space Network, if more information is desired, is Thomas Pirrone or David Massey, phone 215-328-9130.

## 5.6 Ground Components Summary

Considering the ground stations that are expected to exist in 2004, GLAST should be able to obtain support without acquiring new ground stations. The event notification capability will require the acquisition of beamformer and receiver equipment at the TDRSS White Sands Complex. In addition, GLAST will have to provide equipment for planning operations, for monitoring spacecraft and instrument health and for producing Level 0 science data.

The equipment needed for science data analysis, archiving and distribution is not covered in this report.

## 5.7 Ground New Technologies Assessment

No new ground technology is required to support the GLAST mission. Some upgrading of existing sites or development of new sites may be required, but it is assumed these will be implemented before 2004 for other reasons and not charged to the GLAST mission.

## 5.8 Ground Risk Assessment

All ground components for GLAST are within the state of the art, which significantly lowers risk. It is possible that some ground station passes will have to be aborted because of unexpected difficulties, but onboard storage capacity and additional station contact opportunities will allow for retransmission of data when needed. Once the data are received on the ground, transmission protocols will protect against data loss as it is delivered from the receiving site to the ultimate recipient.

The development of the Demand Access capability for TDRSS is still under development, but that should be completed and available for operational support long before GLAST would launch.

## 5.9 Ground Cost Estimate

The specifics of ground system cost for this mission are rather soft. NASA is in the process of establishing a major contract for provision of all operations activities. Economies of scale are expected from this contract which will reduce operations costs for missions, but specifics will not be clearly understood until the contract is established in the second half of calendar 1998. In addition, changes in managing costs as "full cost accounting" is implemented throughout NASA will also influence ground station and operations costs. The remainder of this section will use current cost data, as of January 1998.

Costs in this section include both mission preparation costs and the cost of actually operating the mission.

Mission operations preparation costs include:

- Ground System Development
  This includes provision of one string of control center hardware (it is assumed that the control center hardware will be identical to the I&T hardware, and that one or more of those strings will be moved from the spacecraft development facility to the MOC before launch). Cost could run as high as $500,000, but it is estimated that GLAST could be managed using desktop computer workstations, with a string of equipment costing $30,000 to $50,000. The allocation of functions between the spacecraft and ground system can have significant impact on the ground system acquisition cost.

  If the GLAST purchases a "standard spacecraft" under the Rapid Spacecraft Development Office contract, hardware used for spacecraft I&T may not be available for operations, requiring purchase of a second string of equipment as described above.

- TDRSS support for alert messages and target of opportunity commands.
  Cost of the equipment required to provide the capability discussed in Section 5.4 is estimated at $70,000 per "string." Contact capability within seconds anywhere in the orbit will require 3 "strings" at a total cost of $210,000.

- Operations Preparation
  This includes populating any operations database items which would be in addition to work covered as part of the spacecraft development activity and tailoring of spacecraft Integration & Test procedures for use in orbital operation. It also includes operations simulations and training exercises supported by the MOC. The effort to prepare for operations would typically require about 7 labor years for a mission like GLAST (a cost about $700,000 if current NASA operations costs were used). It is possible that this could be reduced by $50,000 to $100,000 if I&T procedures need very little or no modification to be used for orbital operations. If university personnel were used for this, costs may be different.

**Mission operations costs include:**

- Orbital support by a commercial site, including data transmission to the MOC.
  Universal SpaceNet now operates a ground station in Hawaii, and is planning to develop a site in Southern Florida or the Caribbean. A combination of these sites would provide the required contact time with the two sites providing a backup in case one suffered a major outage. Cost of these sites is estimated to be $350 per pass. Because of the requirement to deliver data to the science analysis function within 24 hours of the measurement, two passes per day will be required. Normal uploads of operational commands can be accomplished during the passes scheduled for return of the science data. That will amount to $255,500 per year or $1,277,500 over 5 years. This is still much cheaper than acquiring and operating a dedicated site.

  Use of Hawaii would be questionable if an orbit inclination of less than 15° can be achieved because this site would add minimal contact time possibility for such an orbit. However, this report is based on an orbit of 28.7° inclination, making Hawaii a very useful site.

- Cost of TDRSS support and data transmission to the MOC.
  There should be no cost for the MA return capability, since special equipment will be installed by GLAST at the White Sands Complex to provide that capability. Use of the TDRSS forward link will be infrequent. For an estimate, it is assumed the TDRSS MA forward link will be required 30 minutes a month, or $1,800 per year.

- Data transmission from the receiving site to the MOC.
  Universal SpaceNet support includes transmitting data from the receiving site to the Washington D.C. area provided it can be done over relatively low-bandwidth lines (T-1 or approximately 1Mbit per second) and can be done so the data transmission can be temporarily interrupted for high priority traffic. It appears that use of this method can still achieve the 24 hour data delivery requirement, so no cost is added for data transmission.

- It appears the MOC can be staffed by no more than two full-time equivalent, 5 days per week persons, making that cost on the order of $200,000 per year. The exact cost will depend on whether commercial contractors or university personnel are used for this function. Also, this cost may be less if GLAST is operated in a multi-satellite control facility where short peaks of attention to GLAST can be averaged with quiet periods.

In summary, the cost of preparing for operation would be $960,000. The cost of operating the mission, using the ground station and control center assumptions discussed, would be $457,300, not including science analysis personnel.

Cost data for typical ground station support and for TDRSS support is included in Tables 5.9.1 and 5.9.2.

| Typical Ground Station Costs | |
|---|---|
| Ground Station Services | Fee per satellite pass (FY97 $) |
| 8 m TOTS at Wallops and Poker Flat | $200 |
| 7.3 m at Wallops | $280 |
| 5 m S-band at Wallops, Puerto Rico and Alaska | $270 |
| 10 m S/X-band Universal Space Net in Hawaii | $350 (see note) |

**Table 5.9.1**: Typical Ground Station Costs

Note: Universal Space Network cost for S/X-band passes has not been fully determined, and the final cost can depend on specifics of the support agreement between NASA and Universal Space Network for the GLAST mission.

| Space Network (TDRSS) Costs | |
|---|---|
| TDRSS Service | Fee per hour (FY97 $) |
| Single Access (S or Ku-band) | $600 |
| Multiple Access (S-band) Forward | $300 |
| Multiple Access (S-band) Return | $60 |
| Service requests which are not TDRSS Flexible Support (see note) | If service requests are not flexible, double the cost above |

**Table 5.9.2**: Space Network (TDRSS) Costs

NOTE: TDRSS Flexible Support requests are requests for contacts which permit NASA Scheduling, at its option, to schedule the requested service at any time during the period of a single orbit of the user mission.